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DEPARTMENT OF DEFENSE

ELECTROMAGNETIC COMPATIBILITY ANALYSIS CENTER

COMMUNICATIONS/ELECTRONICS RECEIVER PERFORMANCE DEGRADATION HANDBOOK

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FOREWORD

The Electromagnetic Compatibility Analysis Center (ECAC) is a Department of Defense facility, established to provide advice and assistance on electromagnetic compatibility matters to the Secretary of Defense, the Joint Chiefs of Staff, the military departments and other DOD components. The Center, located at North Severn, Annapolis, Maryland 21402, is under executive control of the Assistant Secretary of Defense for Telecommunications and the Chairman, Joint Chiefs of Staff, or their designees, who jointly provide policy guidance, assign projects, and establish priorities. ECAC functions under the direction of the Secretary of the Air Force and the management and technical direction of the Center are provided by military and civil service personnel. The technical operations function is provided through an Air Force sponsored contract with the IIT Research Institute (IITRI).

This report was prepared as part of AF Project 649E under Contract F-19628-73-C-0031 by the staff of the IIT Research Institute at the Department of Defense Electromagnetic Compatibility Analysis Center.

To the extent possible, all abbreviations and symbols used in this report are taken from American Standard Y10.19 (1967) "Units Used in Electrical Science and Electrical Engineering" issued by the United States of America Standards Institute.

Users of this report are invited to submit comments which would be useful in revising or adding to this material to the Director, ECAC, North Severn, Annapolis, Maryland 21402, Attention ACV.

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ABSTRACT

The Receiver Performance Degradation Handbook provides reference curves for determining receiver performance as a function of input signal-to-interference ratio. The performance degradation curves were obtained using both simulation models and measured data. The desired signal modulation types considered are A2, A3, A3J, A9B, F1, F3 and F9. The interference modulation types are A1, A3, A3J, A9B, F1, F3, F9, P0 and noise.

KEYWORDS

DEGRADATION
RECEIVER PERFORMANCE
SIGNAL-TO-INTERFERENCE RATIO
ELECTROMAGNETIC COMPATIBILITY

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Frank Kravitz and Emory Harrison of ECAC and Robert Mayher of the Office of Telecommunications (formerly of ECAC) were primarily responsible for the analysis work that preceded the report, and for preparation of the report itself.

Most of the measurements upon which the analysis work was based were provided by the U.S. Army Electronics Proving Ground, Fort Huachuca, Arizona.

The Receiver Waveform Simulation Model, developed by Robert Meyers of ECAC, was used as the primary analytical tool for the generation of the performance curves in this handbook.

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GLOSSARY

a	=	The probability of false alarm
AGC	=	Automatic gain control
AI	=	Articulation Index
AM	=	Amplitude Modulation
AS	=	Articulation Score
A1	=	Amplitude modulation pulsed
A2	=	Two tone pulsed amplitude modulation
A3	=	Amplitude modulated telephony
A3J	=	Single sideband voice, suppressed carrier
A5C	=	TV video
A9B	=	Amplitude modulated composite transmission
β	=	The probability of false dismissal
BAUD	=	One bit per second in a train of binary signals
BW	=	3 dB IF bandwidth (kHz)
BW_{BB}	=	3 dB baseband bandwidth (Hz)
BW_{IF}	=	3 dB IF bandwidth (Hz)
BW_{I}	=	3 dB bandwidth of the interference spectrum
CORODIM	=	Correlation of the recognition of degradation with intelligibility measurements
D_{PK}	=	Maximum frequency deviation
Δf	=	Off-tuned frequency difference between the carriers of the desired and undesired signals
$\overline{\varepsilon^2}$	=	Mean square error
FDM	=	Frequency Division Multiplex
FM	=	Frequency Modulation
FSK	=	Frequency-Shift Keying
F3	=	Frequency modulated telephony
F9	=	Non-specific frequency modulation
GEL	=	General Electronics Laboratory
I	=	Interference signal
$\hat{I}$	=	Peak interference power
IND. DSB-SC	=	Independent double sideband, suppressed carrier
$(\hat{I}/N)$	=	Peak interference power-to-rms noise power ratio in dB

GLOSSARY (Continued)

$(\hat{I}/N)_I$ = Peak interference power-to-mean noise power ratio in dB at the receiver input
ISB = Independent Sideband

K = Decision threshold

L = Lower performance threshold

m = Transmitted message
$\hat{m}$ = Received message
m_I = Interference signal modulation index
m_s = Desired signal modulation index
MIT = Minimum Interference Threshold

N = White Gaussian noise
n = Number of frequency bands in voice spectrum
N_i = Noise power within frequency band i
N_o = Mean noise power in dBm

P_e = Probability of error
PAM = Pulse Amplitude Modulation
PB = Phonetically balanced
PCI = Pattern Correspondence Index
PO = Pulsed carrier modulation
PRF = Pulse repetition frequency
PSI/COMP = Automated AI calculator
PW = Pulse width
PW_I = Pulse width of the interfering pulse in μsec
$P_n(X)$ = Output probability density function with signal, noise and interference present
P9 = Phase shift keyed or phase-lock-loop modulation
P9D = Pulse amplitude modulation

$Q_n(X)$ = Output probability density

$R_I(\Delta f)$ = IF rejection (dB) at the off-tuned frequency Δf
RMS = Root mean square
RWS = Receiver Waveform Simulation

GLOSSARY (Continued)

S	=	Voice power
S_i	=	Voice power within given voice frequency band
SCIM	=	Speech Communications Index Meter
$S(\Delta f)$	=	Relative attenuation of the spectral density (dB) at the off-tuned frequency Δf
(S/I)	=	The mean signal-to-mean interference power ratio in dB
$(S/\hat{I})$	=	The mean signal-to-peak interference power ratio in dB
$(S/I)_I$	=	The mean signal-to-mean interference power ratio in dB at the receiver input (dB)
$(S/\hat{I})_I$	=	The mean signal-to-peak interference power ratio in dB at the receiver input (dB)
$(S/I)_{I,M}$	=	Receiver input signal-to-interference (dB) modified for the effects of off-tuning the interference out of the audio passband and reflected back to the receiver input
$(S/\hat{I})_{I_{PRF}}$	=	The PRF-corrected receiver input mean signal-to-peak interference power ratio (dB)
$(S/\hat{I})_{I_{PW}}$	=	The pulse-width-corrected receiver input mean signal-to-peak interference power ratio (dB)
$(S/I)_o$	=	The mean signal-to-mean interference power ratio at the receiver output (dB)
(S/N)	=	The mean signal-to-mean noise power ratio in dB
$(S/N)_I$	=	The mean signal-to-mean noise power ratio in dB at the receiver input
$(S/N)_{I,B}$	=	The input (S/N) for system with IF 3 dB bandwidth of B
$(S/N)_o$	=	The mean signal-to-mean noise power ratio in dB at the receiver output
SSB	=	Single Sideband
SSB-SC	=	Single Sideband, suppressed carrier
U	=	Upper performance threshold
VIAS	=	Voice Intelligibility Analysis Set

SECTION 1

INTRODUCTION

BACKGROUND

The Electromagnetic Compatibility Analysis Center (ECAC) is engaged in a continuing study of the performance of receiving systems in the presence of various desired and undesired signals. This investigation is part of the Center's effort to formulate methods of electromagnetic compatibility analysis. Parts of this performance evaluation effort have been previously reported (References 1 through 6). Because of a parallel interest in documenting receiver performance criteria, the Office of Telecommunications, U.S. Department of Commerce, through Reference 7, jointly sponsored the development of a degradation handbook.

Criteria are required by EMC engineers in order to readily predict when interference is expected to degrade performance in communications/electronics systems. Such criteria can be presented as degradation thresholds. In order to obtain these thresholds, one must know how receiver output performance varies as a function of receiver input signal-to-interference ratio. A requirement exists for a handbook containing performance degradation curves, and the associated thresholds, to aid the project engineer in analyzing the desired and undesired modulation signals most commonly encountered in interference problems.

OBJECTIVES

The Degradation Handbook is intended to present the EMC analyst with a readily usable set of reference curves for evaluating receiver performance degradation.

A long term objective is to prepare performance degradation data for all desired-to-interference modulation categories described by an X in TABLE 1-1. The cases covered in this initial report are also indicated in the table.

APPROACH

The digital error probability model (Reference 1, Sections 11 and 12) and the Receiver Waveform Simulation (RWS) model (Reference 6) were used in conjunction with appropriate measured data (Reference 8) to formulate the relationship between output performance degradation and input signal-to-interference power ratio.

TABLE 1-1

DESIRED/INTERFERENCE MODULATION CASES COMPLETED
FOR THE PERFORMANCE DEGRADATION HANDBOOK

Desired \ Undesired	Modulation Description†	A1	A2	A3	A3J	A5C	A9B	F1	F3	F9	PO	Noise
A1	CW Telegraphy	X					X	X	X	X	X	X
A2	2-Tone Telegraphy	(X)	X	(X)			(X)	X	(X)	X	X	(X)
A3	Voice	(X)		(X)	(X)		(X)	(X)	(X)	(X)	(X)	(X)
A3J	SSB-SC Voice	(X)		(X)	(X)		(X)	(X)	(X)	(X)	(X)	(X)
A5C	TV Video	X				X	X	X	X	X	X	X
A9B	4 ISB Voice Channels			(X)			(X)	(X)		(X)	(X)	(X)
F1	FSK Telegraphy (2 Frequencies)	(X)		(X)			(X)	X	(X)	X	(X)	(X)
F3	Voice (no de-emphasis)	(X)		(X)	(X)		(X)	(X)	(X)	(X)	(X)	(X)
F3	Voice (with de-emphasis)	X					(X)	(X)	(X)	(X)	X	(X)
F9	FDM (12 voice channels)	(X)		(X)			(X)	(X)	(X)	(X)	(X)	(X)
F9	Wideband Telemetry						X	X	X	X	X	X
F9	PCM	X		X			X		X	X	X	X
F9	(Phase Lock Loop Receiver)	X					X	X	X	X	X	X
PO	Pulse	X					X	X	X	X	X	X
P9	Spread Spectrum	X					X	X	X	X	X	X

Note:

X Indicates cases to be covered by long term objective.

(X) Cases completed and covered herein.

† Describes specific cases analyzed.

For each modulation category, the relationship between output degradation and input signal-to-interference ratio was prepared for:

1. Two specific input signal-to-noise ratios, a low signal-to-noise ratio representing reception at the receiver sensitivity level, and a high signal-to-noise ratio representing good quality reception. In both cases, the signal-to-noise ratio was maintained constant and independent of the interference signal level as the interference signal level was varied throughout the span of each performance degradation curve.
2. Three cases of relative tuning between the desired and undesired signal:

    a. Cochannel on-tune (interfering carrier frequency approximately coincides with desired signal carrier)
    b. Cochannel off-tuned (interfering carrier tuned within the information 3 dB-bandwidth of the receiver)
    c. Adjacent signal (interfering carrier off-tuned between the frequencies of the 3 dB and the 80 dB IF rejection levels of the receiver).

3. Two specific performance thresholds were defined for each performance degradation curve (an upper and a lower performance threshold). These thresholds indicate the points on the curve where the interference levels reach values sufficient to degrade receiver performance by specified amounts. The threshold levels, and the specific terminology used to describe receiver performance above and below the thresholds, differ from case to case depending upon the type of desired and/or interference signal.

SECTION 2

SYNOPSIS

SYNOPSIS

The techniques used to obtain and apply the performance degradation curves are discussed in the Analysis Section, which contains the following:

1. The Discussion subsection contains a discussion of the logic used in transferring desired and interference signals through the receiver components.
2. The Procedure subsection explains the basis for the equipment characteristics chosen and contains the procedure used to obtain the degradation curves.
3. The Application subsection discusses the techniques needed to use the degradation curves, including their possible extension to parameters which were not analyzed.

The appendices of the handbook contain the information needed to predict performance degradation for the specified desired-to-interference signal cases. The Degradation Measures section (APPENDIX I) describes the different types of performance degradation considered. Included are discussions and definitions of articulation score (AS), articulation index (AI), minimum interference threshold (MIT), error probability and mean square error.

APPENDIX II contains the equipment characteristics for the receivers analyzed, and descriptions of the desired and interference signals considered. APPENDIX III contains a brief description of a sample degradation curve, and the degradation curves for the desired-to-interference signal cases analyzed to date.

SECTION 3

ANALYSIS

DISCUSSION

The starting point for the performance degradation analysis of a receiver is to define the decision mechanism. This definition involves deriving and/or measuring the intelligibility of the output information as a function of the output desired signal-to-undesired signal (signal-to-interference) power ratio. The formulation of receiver performance degradation begins at the decision mechanism and works backward through the receiving system elements toward the input of the receiver.

The derivation of receiver performance degradation can be viewed as a three-step operation, shown symbolically in Figure 3-1. The first step derives the output information intelligibility as a function of output signal-to-interference power ratio. The second step derives the power transfer functions of various receiver stages. These transfer functions show the relationship between the input and output signal-to-interference ratios. The third step combines the previous two steps and transforms the output information intelligibility to a function of the input signal-to-interference ratio.

Receiver performance degradation can be determined at three locations in the signal path, as shown in Figure 3-2. The first location occurs at the IF output, which is also the input to the second detector. Determining the degradation relative to desired and interference signal levels at the second detector input is useful for basic theoretical considerations. The problem at the second detector becomes that of operating on the desired and undesired signals by nonlinear and linear transfer functions of the second detector, low pass filter and receiver decision mechanism. The degradation solution at this point remains independent of RF and IF filter characteristics. On the other hand, differences from one receiver to another in the RF and IF filter characteristics modify the transfer of interference power through the receiver to the IF output, and so the interference power must be calculated for each separate case. When the RF and IF transfer characteristics are included, the detector input degradation characteristics can be reflected back to the receiver input point, and the complete receiver input degradation curves are obtained.

The second location is at the input to the IF amplifier. Performance degradation specified for this location includes the effects of the IF filter, second detector and decision mechanism. The solution of a problem

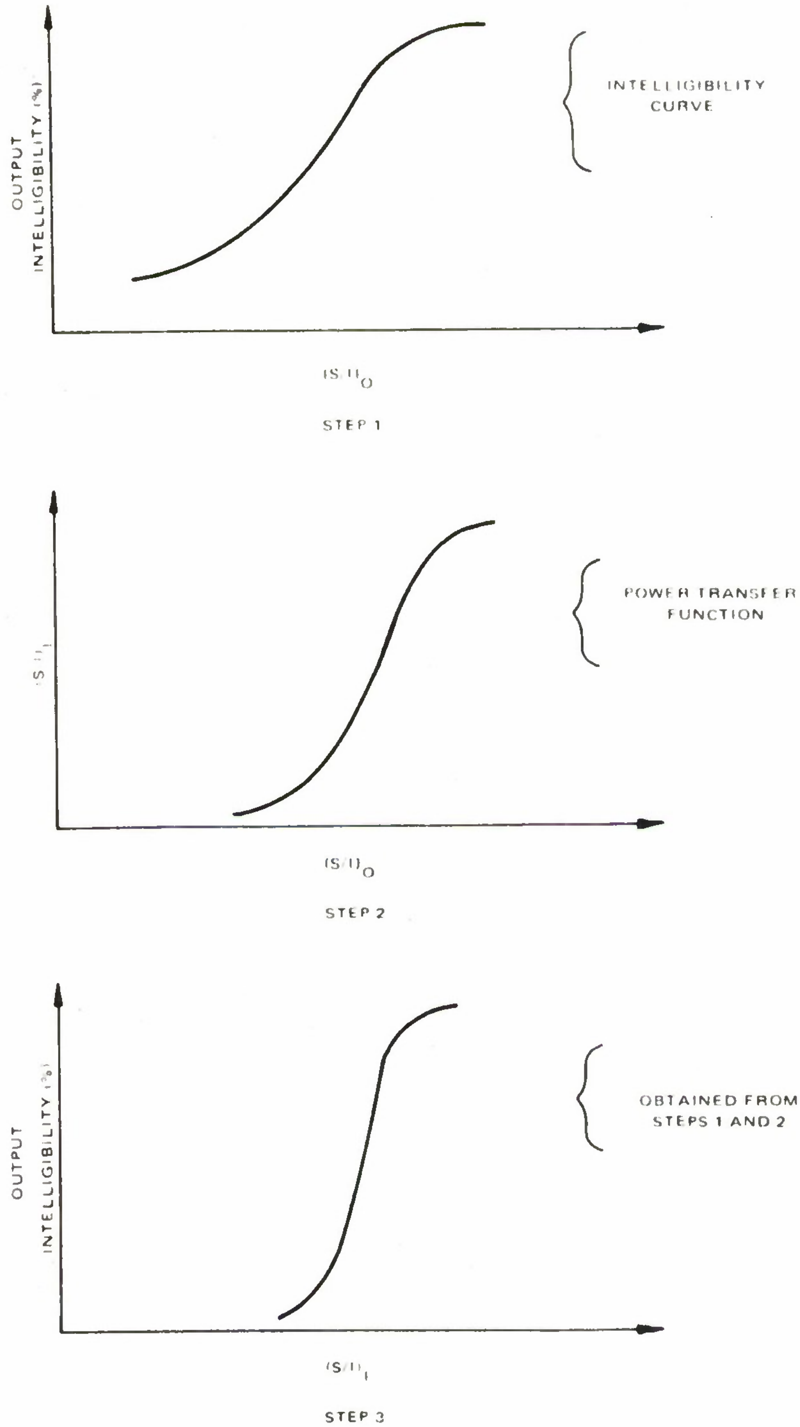


Figure 3-1. Synthesized Performance Degradation Procedure

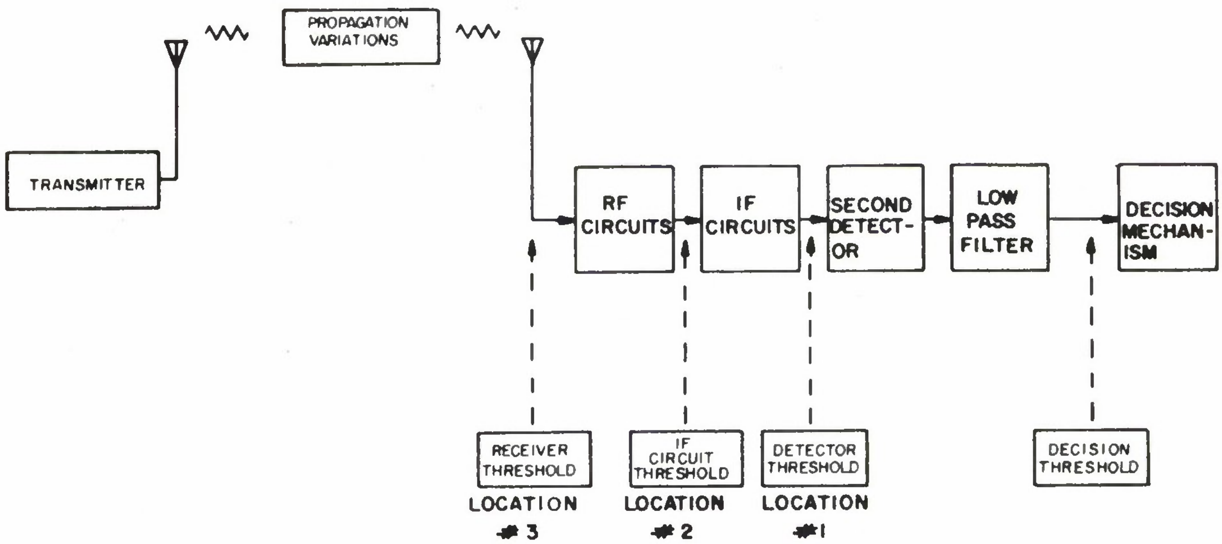


Figure 3-2. Various Receiver Degradation Analysis Locations

at this location is usually the same as the solution at the receiver input when RF nonlinearities are not significant. This is true because the filtering effect of the cascade of RF and IF amplifiers is approximately equal to the overall effect of the IF amplifiers taken alone. Receiver degradation models at this location are convenient to analyze and use in interference prediction.

The third location is at the input to the receiver. Performance analysis at this location can be complicated if cross modulation, intermodulation, spurious response and saturation problems are considered. These problems typically involve nonlinear effects, including the effects of high power interfering signals at frequencies outside the IF bandpass region. Such nonlinear analysis is outside the scope of this handbook.

The degradation curves contained in APPENDIX III were obtained at the second and third locations discussed above. The Receiver Waveform Simulation (RWS) model (Reference 6) uses the second location (the IF input) when analyzing performance degradation. However, most measured data was taken at the third location (the receiver input). The agreement between the measured data and the outputs of the RWS model indicates that the two locations (second and third) give identical results for a restricted range of interference frequencies.

The second location (IF input) is the same as location three (receiver input) if the RF amplifiers have no effect, which will be true when the interference is tuned between the frequencies of the 80 dB rejection level of the IF amplifiers. Within these tuning limits, the degradation at the receiver input location is relatively easy to analyze, to validate with measurements, and to use in interference prediction problems. The performance degradation solution at this point becomes essentially the same as the IF input solution. The curves in APPENDIX III provide performance degradation as a function of input signal-to-interference ratio $(S/I)_I$, even though the analysis was performed at the input to the IF in some cases. The generalized receiver model used is shown in Figure 3-3.

This Degradation Handbook does not attempt to provide performance degradation measures for interference tuned outside the frequencies of the 80 dB rejection level of the IF filter. The solution of this type of problem however, can be obtained by performing a separate RF nonlinear analysis to determine the structure and rejection level of the translated (or shifted) interfering signal as it would appear at the IF input. It is then practical to use the appropriate modulation case in the handbook with the interference level modified by the effective rejection level.

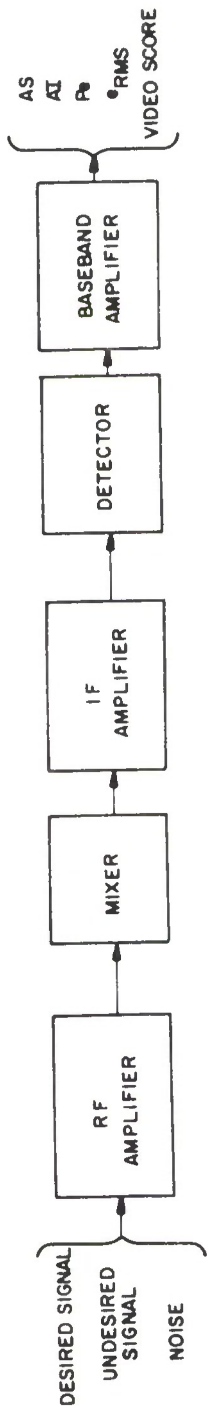


Figure 3-3. Components Modeled To Obtain Performance Degradation

The usual input for solving a problem using the Degradation Handbook will be discrete values of signal and interference power. The performance degradation resulting from the discrete, or deterministic, signal-to-interference ratio will also be a discrete (or single) value. However, for some interference prediction problems, the input signal-to-interference ratio is described in statistical terms. There are two methods of using the handbook curves for "probabilistic" input signal-to-interference ratios $(S/I)_I$.

The first approach is to use a "conditional" signal-to-interference ratio to obtain a single value of performance degradation. A single S/I value is selected from the input S/I distribution to obtain a single performance degradation value. An example of this type of description is, "the S/I value which will result in an articulation index (AI) of 0.68 or higher 99% of the time". This performance degradation value must be carefully labeled with the appropriate conditional probability obtained from the input S/I probability distribution.

The second method of using a probabilistic input S/I with the handbook curves is to combine the entire S/I probability density function with the performance degradation curve. This procedure obtains the performance probability density function (probability of occurrence of a specific performance degradation).

PROCEDURE

The purpose of the Degradation Handbook is to present the EMC analyst with a readily usable set of reference curves for evaluating receiver performance degradation. The performance degradation curves were developed from a combination of measured data, theoretical analysis and outputs from the RWS and digital error probability models. These curves describe the degradation of the receiver output information in terms of a degradation measure (i.e., bit error probability for digital systems, articulation score (AS) and articulation index* (AI) for voice systems, mean square error for analog systems, etc.) as a function of the input desired signal-to-interference power ratio. The relative power levels of the desired and interference signals are those occurring at the receiver input.

The equipment characteristics and signal parameters used to develop the degradation curves were those most representative of each modulation type. For some modulation types, the signal and receiver parameters vary greatly from equipment to equipment; therefore, one representative set

* A discussion of AS and AI is provided in APPENDIX I.

of parameters was picked. The parameters were chosen after a search through the C&E Directory (Reference 21) to determine the most representative under operational conditions. This procedure was necessary because the large number of possible combinations of receiver and signal parameters does not permit them all to be represented by individual curves. The size of the handbook would become excessive. Also, some of the possible combinations have a low probability of occurrence in a real situation. Therefore, an effort was made to select the most commonly occurring receiver parameters and modulation parameters for each category of desired signal and interference modulation.

The equipment parameters chosen may not represent the parameters for a particular problem. If one has a problem involving parameters which differ from those used in the generation of the degradation curves, a separate analysis may be required to obtain accurate performance degradation. Some variations in the parameters can be accounted for by applying equations to modify the degradation curves. In particular, modifications can be made to the degradation curves to account for different IF bandwidths, pulsed interference characteristics, and in some instances different wideband (F9 or PO) interference characteristics. The possible modifications are discussed later in more detail.

APPLICATION

In order to use the handbook it is necessary to calculate the receiver input signal-to-interference ratio. The ratio is then used with the appropriate Degradation Handbook curve (for cochannel interference) to obtain the level of performance at the output of the victim receiving system. The adjacent signal interference must be modified to represent the effect of the IF filter on the interference and the effect of the audio filter on the combination of the desired and undesired signals. In some instances, the degradation curves must be modified to account for parameters different from the parameters used to obtain the curves.

Degradation curves are provided for two input signal-to-noise $[(S/N)_I]$ ratios, two degradation thresholds and three frequency separations (i.e., off-tunings) between the desired and interference signal.

The two input signal-to-noise ratios are for the cases of an output signal-to-noise ratio representing good quality (25 dB for a voice system) and a minimum usable output (10 dB for a voice system)*. These two cases bracket the range of possible usable output signal-to-noise ratios

* The 10 dB (S/N) ratio also corresponds to a realistic definition of sensitivity.

encountered in most receivers.

The degradation curves contained in APPENDIX III are presented in terms of a continuous range of AS and AI scores for voice systems, and bit error probability (P_e) for digital systems. In an actual case, almost any criterion of AS, AI or P_e might be used to separate acceptable and unacceptable communications performance. The handbook is limited in size by practical considerations but two thresholds are provided in each case in an effort to include as many situations as possible. The upper threshold denotes the separation between acceptable and marginal performance for analog interference, and between acceptable and tolerable performance for digital interference. The lower threshold denotes the separation between marginal and unacceptable performance for analog interference, and between tolerable and marginal performance for digital interference. The two thresholds in each case are a function of the type of information (voice, analog, digital, etc.) transmitted by the desired system and the type of interference signal (analog, digital, pulsed, etc.). The two thresholds for the various desired and interference signal combinations are listed in TABLE 3-1.

TABLE 3-1

PERFORMANCE THRESHOLDS FOR VARIOUS DESIRED AND INTERFERENCE COMBINATIONS

	CW OR ANALOG INTERF.		PULSED OR DIGITAL INTERF.	
DESIRED MODULATION	UPPER	LOWER	UPPER	LOWER
Voice Modulated Desired Signal	0.7 AI*	0.3 AI*	MIT**	0.7 AI**
Digital Desired Signal***	$10^{-4} P_e$	$10^{-2} P_e$	$10^{-4} P_e$	$10^{-2} P_e$

* From a Bell Aerosystems Company study of voice communications scoring procedures, done for USAEPG, Ft. Huachuca, Arizona.

** From Reference 5

*** These upper (10^{-4}) and lower (10^{-2}) bit error probability values are within the digital interference threshold criteria used by CCIR.

The thresholds for a voice modulated desired signal with analog interference are based on articulation score criteria and are defined in terms of the more easily obtained AI values. The thresholds for pulsed interference to voice modulated signals are based on operator fatigue criteria

and are defined in terms of the more easily obtained AI and MIT values (see APPENDIX I for MIT definition). The degradation curves in APPENDIX III are divided into performance regions by the threshold criteria discussed here. For voice desired signals, the thresholds, and the labels for the regions defined by the thresholds, are different for the cases of analog interference and digital interference. The thresholds for digital desired signals are based on average interference power criteria and the same thresholds can be used for pulsed and analog interference.

Performance degradation was investigated for three cases of frequency separation between the desired and interfering signals; a cochannel on-tune case, a cochannel off-tuned case (worst case) and an adjacent signal case. These cases bracket the range of possible interference tuning involved in most interference problems.

A summary of the performance degradation thresholds presented in this handbook is given in TABLES 3-2 and 3-3, and the complete degradation curves are contained in APPENDIX III. TABLES 3-2 and 3-3 show the input signal-to-interference values representing the upper and lower performance thresholds. TABLE 3-2 gives the cochannel performance thresholds for the cochannel on-tune case (i.e., when the frequency difference between the desired and interference carriers is approximately zero). TABLE 3-3 gives the cochannel performance thresholds for the cochannel off-tuned (worst) case (i.e., when the frequency difference between the desired and interference carriers is approximately 500 Hz). Both tables contain information for two signal-to-noise ratios which would normally (in the absence of interference) represent a high (good quality) input signal level and a low (sensitivity) signal level. The adjacent signal cases (interference tuned between the frequencies of the 3 dB and 80 dB rejection levels of the IF skirt) are not included in the table because these performance thresholds vary with the frequency difference between the desired signal and the interference.

The degradation curves included in the report are in many cases applicable to more than one off-tuning category. For example, the degradation for P0 or F9 interference does not change as the interference is off-tuned. As a result, only one degradation curve is provided for these cases. The figure number of the proper curve to use for each situation (desired signal, interference, Δf) is given in TABLE 3-4. In addition to the figure number of the curve, the equation describing any modification of the curve for adjacent signal cases is included. The adjacent signal case is defined as interference between the frequencies of the 3 dB and 80 dB rejection level of the IF selectivity curve.

TABLE 3-2

$(S/\hat{I})_I$ THRESHOLD VALUES (dB) FOR COCHANNEL ON-TUNE INTERFERENCE ($\Delta f = 0$)

DESIRED \ INTERFERENCE			A1*		A3		A3J		A9B		F1*		F3		F9		PO*		NOISE	
	$(S/N)_1$	$(S/N)_o$	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L
A2	18		4	4	5	5			4	4			4	4					5	4
	7		5	4	5	4			5	5			6	5						
A3	35	25	34	4	7	2	17	6	9	3	38	4	19	8			10	-18	21	10
	20	10	20	NA	NA	3	10	8	NA	3	24	0	NA	8			-6	NA		
A3J	25	25	16	-14	-14	-28	2	-12	-12	-26	20	-24	3	-10	0	-12	-10	-38	10	-4
	10	10	0	-6	-6	-28	10	-12	-8	-26	6	2	13	-10	14	-12	-24	-30		
A9B	30	20			8	3	NA	5	6	0	28	6			19	7	-10	-22	20	6
	20	10			13	3	NA	5	8	0	18	NA			30	7	-14	NA		
F1	18		0	0	3	2			1	1			1	1			-49	-50	9	6
	7		3	2	3	2			4	3			5	3			-39	-40		
F3 No De-Emphasis	22	25	26	4	7	0	8	0	4	0	34	10	6	0	8	0	-11	-24	8	2
	8	10	14	NA	15	0	18	2	12	2	18	18	12	0	17	2	-16	NA		
F3 With De-Emphasis	22	43							2	-4	32	2	2	-5	3	-4			2	0
	8	25							4	-2	20	3	4	-4	4	2				
F9	25	25	27	3	4	0			4	0	34	6	12	2	2	0	5	-66	8	2
	10	10	16	10	10	1			10	0	20	10	16	2	10	2	-13	-42		

NOTE:
L = Lower Performance Threshold.
U = Upper Performance Threshold.
* = For the pulsed interference cases, the threshold values are in terms of $(S/\hat{I})_1$.

TABLE 3-3

$(S/I)_I$ THRESHOLD VALUES (dB) FOR COCHANNEL OFF-TUNED INTERFERENCE (Δf = 500 Hz)

DESIRED \ INTERFERENCE			A1*		A3		A3J		A9B		F1*		F3		F9		PO*		NOISE	
	$(S/N)_I$	$(S/N)_O$	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L
A2	18		4	4	5	5			4	4			4	4					5	4
	7		5	4	5	4			5	5			6	5						
A3	35	25	50	8	8	3	14	3	11	4	45	8	19	8			10	18	21	10
	20	10	33	NA	NA	4	NA	5	NA	5	30	NA	8	NA			-6	NA		
A3J	25	25	32	-8	-5	-19	4	-16	10	-5	30	-12	3	-10	0	-12	-10	-38	10	-4
	10	10	18	12	11	-17	14	-15	+18	-5	16	-12	13	-10	14	-12	-24	-30		
A9B	30	20			13	4			12	5	32	10			19	7	-10	-22	20	6
	20	10			35	4			27	5	18	NA			30	7	-14	NA		
F1	18		0	0	3	2			1	1			1	1			-49	-50	9	6
	7		3	2	3	2			4	3			5	3			-39	-40		
F3 No De-Emphasis	22	25			8	1	8	1	4	0	34	8	6	0	8	0	-11	-24	8	2
	8	10			20	2	18	2	12	2	18	18	12	0	17	2	-16	NA		
F3 With De-Emphasis	22	45							2	-4	32	2	2	-5	3	-4			2	0
	8	25							4	-2	20	3	4	-4	4	-2				
F9	25	25	40	12	14	4			14	5	40	14	18	6	4	-4	0	-34	8	2
	10	10	30	16	20	4			30	5	36	22	22	6	20	-4	-22	-26		

NOTE:
L = Lower Performance Threshold,
U = Upper Performance Threshold.
* = For the pulsed interference cases, the threshold values are in terms of $(\hat{S/I})_I$

TABLE 3-4

LOCATION OF DEGRADATION CURVE FOR EACH DESIRED SIGNAL-TO-INTERFERENCE CASE

DESIRED	UNDESIRED	A1	A3	A3J	A9B	F1	F3	F9	PO	NOISE
A2	On-Tune Cochannel Off-Tune Cochannel Adjacent Signal	III-2 3-1/III-2	III-3 3-2/III-3		III-4 3-2/III-4		III-5 3-1/III-5			III-6
A3	On-Tune Cochannel Off-Tune Cochannel Adjacent Signal	III-7 III-8 3-1/III-7	III-11 III-12 3-2/III-11	III-13 III-14 3-4/III-13	III-15 III-16 3-2/III-15	III-17 III-18 3-1/III-17	III-19 3-1/III-19		III-21 III-22 3-1/III-21	III-20
A3J	On-Tune Cochannel Off-Tune Cochannel Adjacent Signal	III-23 III-24 3-1/III-23	III-27 III-28	III-29 III-30 3-1/III-29	III-31 III-32 III-31	III-33 III-34 3-1/III-33	III-35	III-36	III-38 3-1/III-38	III-37
A9B	On-Tune Cochannel Off-Tune Cochannel Adjacent Signal		III-39 III-40 3-2/III-39		III-41 III-42 3-2/III-41	III-43 III-44 3-1/III-43		III-45	III-47 3-1/III-47	III-46
F1	On-Tune Cochannel Off-Tune Cochannel Adjacent Signal	III-48 3-1/III-48	III-49 3-1/III-49		III-50 3-1/III-50		III-51 3-1/III-51		III-53 3-1/III-53	III-52
F3 No De-Emphasis	On-Tune Cochannel Off-Tune Cochannel Adjacent Signal	III-54 3-3/III-54	III-55 III-56 3-3/III-55	III-57 3-3/III-57	III-58 3-3/III-58	III-59 III-60 3-1/III-59	III-61 3-1/III-61	III-62	III-64 3-1/III-64	III-63
F3 De-Emphasis	On-Tune Cochannel Off-Tune Cochannel Adjacent Signal				III-65 3-3/III-65	III-66 3-1/III-66	III-67 3-1/III-67	III-68		III-69
F9	On-Tune Cochannel Off-Tune Cochannel Adjacent Signal	III-70 III-71 3-3/III-70	III-74 III-75 3-3/III-74		III-78 III-79 3-3/III-78	III-82 III-83 3-3/III-82	III-86 III-87 3-3/III-86	III-90 III-91 3-3/III-90	III-95 III-96 3-1/III-95	III-94

Because TABLE 3-4 is important in selecting the proper degradation curve, a brief description is included here. For each combination of desired and interference modulation, three conditions of interference off-tuning with respect to the desired signal carrier frequency are listed. For each tuning condition, the figure number of the appropriate curve in APPENDIX III is given. In some adjacent signal conditions the curve given by the figure number must be modified by an equation. For these cases, the equation number precedes the figure number.

In some cases, a single figure number is given because the curve for the cochannel on-tune condition is also applicable to the cochannel off-tune and/or adjacent signal conditions. In the case of white noise interference, one figure number is listed because tuning differences do not matter for broadband noise. Cases that have not been analyzed are indicated by an X.

The cochannel interference degradation curves may be used directly in an analysis to obtain performance degradation as a function of $(S/I)_I$. However, the adjacent signal interference case usually requires several more steps in order to obtain the degree of performance degradation. It will not be necessary to describe each desired-to-interference case because the cases can be divided into several distinct categories. That is, desired signals can be placed into categories of very narrowband (F1), narrowband (A2, A3, A3J, A9B, F3 voice), and wideband (F9). Interference signals can be placed into categories of narrowband (A1, A3, A3J, A9B, F1, F3) and wideband (F9, PO, Noise).

Other modulation types are wide compared to the narrow filters used for digital desired signals (F1). In addition, the narrow IF bandwidth (less than 1 kHz) and its associated sharp selectivity (typically ten double-tuned stages) remove the cochannel off-tune and adjacent signal cases from consideration. The only important criterion for the very narrowband (F1) digital desired signal cases is the interference power within the receiver IF pass band. To determine this, one must know the interference spectral density. Knowing the spectral density, one can calculate the interference power in the IF pass band when the interfering signal is at the adjacent signal frequency, relative to the power in the IF pass band for on-tune interference. The cochannel on-tune performance degradation curve can then be used by subtracting the attenuation of the interference from the signal-to-interference ratio at each degradation value.

$$(S/I)_{I,M} = (S/I)_I + S(\Delta f), \quad BW_I > BW \tag{3-1}$$

where:

$(S/I)_{I,M}$ = Receiver input signal-to-interference ratio (dB), modified for the effects of off-tuning the interference out of the audio pass band, and reflected back to the receiver input

$(S/I)_I$ = Receiver input signal-to-interference ratio (dB) given in the handbook

$S(\Delta f)$ = Relative attenuation of the interference signal spectral density (dB) for the off-tuned frequency, Δf

BW_I = 3 dB bandwidth of the interference spectrum

The next category of desired signals to be discussed is narrowband voice signals. For wideband interference to narrowband voice desired signals, the interference spectral density is constant out to the adjacent signal off-tuned frequency. Therefore, the interference rejected by the IF selectivity is also constant out to the adjacent signal off-tuned frequency, and the cochannel on-tune degradation curve is applicable for all three regions. For the case of narrowband interference to narrowband voice desired signals, separate curves are required for cochannel, on-tune and off-tuned interference because the differences in performance degradation are significant (greater than 3 dB). The adjacent signal interference cases give results which are a function of the rejection of the IF filter at the off-tuned frequency and the frequency components which lie within the audio pass band of the receiver. For the A3 to A3 adjacent signal case the following equation, derived from Equation (4-1) of Reference 1, is used [for other applications of Equation (3-2) see TABLE 3-4]:

$$(S/I)_{I,M} = \tfrac{1}{2}\,(S/I)_I + R_{IF}\,(\Delta f) \qquad (3\text{-}2)$$

where:

$(S/I)_{I,M}$ = Receiver input signal-to-interference ratio (dB), modified for the effects of off-tuning the interference out of the audio pass band, and reflected back to the receiver input

$(S/I)_I$ = Receiver input signal-to-interference ratio (dB) given in the handbook

$R_{IF}(\Delta f)$ = IF rejection (dB) at the off-tuned frequency, Δf (limited to rejection levels between -3 and -80 dB)

The case of an A3 receiver with A3 interference will be used as an example to illustrate the calculation of the adjacent signal performance degradation. As can be seen in TABLE 3-4, the same curve applies to the cochannel on-tune and the adjacent signal degradation cases. However, in the adjacent signal case the curve must be modified to account for the effects of off-tuning the interference beyond the 3 dB bandwidth of the IF filter. This modification is accomplished using the equation referenced in TABLE 3-4 [Equation (3-2)].

If the $R_{IF}(\Delta f)$ = -60 dB and the $(S/I)_I$ = 6 dB for a 0.7 AI, the value of $(S/I)_{I,M}$ = -57 dB for a 0.7 AI threshold. This means that interference off-tuned from the desired signal to a frequency where it is 60 dB down on the IF selectivity curve will require an $(S/I)_{I,M}$ = -57 dB for a 0.7 AI threshold.

Analysis of some of the other narrowband systems, interfered with by narrowband interference, will require a more simplified version of Equation (3-2).

$$(S/I)_{I,M} = (S/I)_I + R_{IF}(\Delta f) \qquad (3\text{-}3)$$

where:

$(S/I)_{I,M}$ = Receiver input signal-to-interference ratio (dB), modified for the effects of off-tuning the interference out of the audio pass band, and reflected back to receiver input

$(S/I)_I$ = Receiver input signal-to-interference ratio (dB) given in the handbook

$R_{IF}(\Delta f)$ = IF rejection (dB) at the off-tuned frequency, Δf (limited to rejection levels between -3 and -80 dB)

The multiplex FM (F9) desired signal cases analyzed herein have a wideband desired modulating signal (12 voice channels) and narrowband interference will degrade different channels as the interference is off-tuned. Therefore, performance degradation levels are provided only for the lowest and the highest of the 12 voice channels. For narrowband interference tuned outside the IF 3 dB bandwidth, Equation (3-3) would apply. For wideband interference, a determination must be made as to which has greater significance, the IF filter or the spectral density fall-off. The smaller value of the two would then be used as the final term in Equation (3-1) or (3-3), as applicable.

Another special case is the A3 receiver with A3J interference. The adjacent signal interference case has the form:

$$(S/I)_{I,M} = \frac{[(S/I)_I -10]}{2} + R_{IF}(\Delta f) \qquad (3\text{-}4)$$

where:

$(S/I)_{I,M}$ = Receiver input signal-to-interference ratio (dB), modified for the effects of off-tuning the interference out of the audio passband, and reflected back to the receiver input

$(S/I)_I$ = Receiver input signal-to-interference ratio (dB) given in the handbook (10 dB is subtracted to account for the fact that A3J interference has 10 dB more power in the sidebands than the A3 desired signal)

$R_{IF}(\Delta f)$ = IF rejection (dB) at the off-tuned frequency, Δf (limited to rejection levels between -3 and -80 dB)

In the case of a narrowband voice receiver analysis, radar and digital data adjacent signal interference that is outside the IF pass band follows the fall-off of the interfering spectrum. This occurs because the interference spectrum is approximately constant across the receiver IF bandwidth (Reference 5). In addition, the IF rejection at the tuned frequency of the interference will exceed the spectral fall-off in the IF pass band. The degradation effect is primarily caused by the power of the interference in the IF pass band, and the degradation follows the spectral fall-off.

The on-tune and off-tuned cochannel A3J receiver cases are similar to the A3 receiver cases. However, the adjacent signal cases that are outside the IF bandwidth of the A3J receiver have not been calculated since the IF fall-off rate of the receivers examined was extremely steep and would not require an adjacent signal degradation evaluation.

The pulse interference curves that are given in the handbook were calculated for pulse widths (PW) and pulse repetition rates (PRF) that are representative of this category. In order to modify these results to account for different PW's and PRF's, it is necessary to correct the input signal-to-peak-interference ratio $[(S/\hat{I})_I]$ scale by the duty cycle and, in addition, to limit or restrict these corrections where applicable. In

particular, for changes in PW, it is required that

$$\hat{(S/I)}_{I_{PW}} = \hat{(S/I)}_1 + 20 \log \frac{PW_I}{5}, \text{ for } PW_1 < \frac{10^3}{BW}$$

$$= \hat{(S/I)}_1 + 10 \log \frac{PW_I}{5} + 14, \text{ for } PW_1 > \frac{10^3}{BW} \qquad (3\text{-}5)$$

where:

$\hat{(S/I)}_{I_{PW}}$ = Receiver input signal-to-peak-interference ratio (dB), corrected for change in pulse width

PW_I = Pulse width of the interfering pulse in μs

BW = IF bandwidth (kHz)

For changes in PRF

$$\hat{(S/I)}_{I_{PRF}} = \hat{(S/I)}_1 + 10 \log \frac{PRF}{300}, \text{ for PRF} < 1000 \text{ pps} \qquad (3\text{-}6)$$

where:

$\hat{(S/I)}_{I_{PRF}}$ = Receiver input signal-to-peak-interference ratio (dB), corrected for changes in PRF

PRF = The pulse repetition frequency in pulses per second

The A3 receiver used in the analysis had an IF 3 dB bandwidth of 8 kHz. Some A3 receivers have a bandwidth wider than 8 kHz and these receivers, with some modification of the input parameters, can be analyzed using the same performance degradation curves. The input desired signal-to-noise ratio, $(S/N)_1$, must be determined for an equivalent 8 kHz bandwidth.

In general, if the $(S/N)_{I,BW}$ is given for a 3 dB bandwidth wider than B kHz (the bandwidth used to generate the curve), the equivalent $(S/N)_I$ for a system having a bandwidth of B kHz would become

$$(S/N)_1 = (S/N)_{I,BW} + 10 \log \frac{BW}{B}, \text{ for BW} > \text{B kHz} \qquad (3\text{-}7)$$

where:

$(S/N)_I$ = Input S/N (dB) for a system with an IF 3 dB bandwidth of B kHz

$(S/N)_{I,BW}$ = Input S/N (dB) for a system with IF 3 dB bandwidth of BW

BW = IF bandwidth (kHz) of receiver being analyzed

B = IF bandwidth (kHz) used for degradation curve (for the A3 receiver curves, B = 8 kHz)

The $(S/N)_I$ calculated from the previous equation is used to determine the appropriate degradation curve for A3 receivers. The curve may be used without modification for narrowband interference (A1, A3, A3J, A9B, F1). For wideband interference (F3, F9), the $(S/I)_I$ must be similarly changed by

$$(S/I)_I = (S/I)_{I,BW} + 10 \log \frac{BW}{B}, \text{ for } BW > B \text{ kHz} \tag{3-8}$$

where:

$(S/I)_{I,BW}$ = Input signal-to-interference ratio (dB) for system with IF 3 dB bandwidth of BW

$(S/I)_I$ = Input signal-to-interference ratio (dB)

BW = IF bandwidth (kHz) of receiver being analyzed

B = IF bandwidth (kHz) used for degradation curve

For pulsed interference (AI and PO) the input signal-to-peak-interference $(S/\hat{I})_{I,BW}$ must be modified

$$(S/\hat{I})_I = (S/\hat{I})_{I,BW} + 20 \log \frac{BW}{B}, \text{ for } BW > B \text{ kHz} \tag{3-9}$$

where:

$(S/\hat{I})_I$ = Receiver input signal-to-peak-interference ratio (dB)

$(S/\hat{I})_{I,BW}$ = Input $S/\hat{I}$ (dB) for a system with IF 3 dB bandwidth BW

BW = IF bandwidth (kHz) of receiver being analyzed

B = IF bandwidth (kHz) used for degradation curve

The above modifications to the degradation curves can also be made for A2, A3J, and A9B receivers using the appropriate 3 dB IF bandwidth (BW) of the desired receiver and the IF bandwidth (B) used for the degradation curve.

As an example, let us examine the case of a single sideband receiver (A3J) subjected to interference from a radar (PO). The assumed desired signal and receiver parameters are:

1. BW_{IF} = 2.7 kHz (ten double-tuned stages)
2. BW_{BB} = 0.3-3 kHz (six low- and six high-pass stages)
3. Noise Figure = 10 dB

The assumed interference parameters are:

1. Pulse width = 5 μs
2. Pulse repetition frequency = 200 pps
3. Peak interference power at the receiver is -70 dBm

For this particular example, the interference (PO) is wideband and the interference power is constant across all tuning conditions considered in the analysis. That is, the approximately 130 kHz bandwidth of the interference means the degradation will be constant out to 65 kHz of off-tuning. This is much wider than the frequency of the 80 dB point on the IF selectivity curve.

The first parameter to determine is the IF output noise power in the receiver:

$$N_o(\text{dBm}) = KT_o\ (\text{dBm/Hz}) + 10 \log BW_{IF}(\text{Hz}) + \text{Noise Figure (dB)}$$

$$= -174 + 34 + 10$$

$$= -130 \text{ dBm}$$

where:

N_o = Receiver noise power

K = Boltzmann's constant

The $\hat{I}/N$ at the receiver input is

$$(\hat{I}/N)_I = -70 \text{ dBm} - (-130 \text{ dBm})$$

$$(\hat{I}/N)_I = 60 \text{ dB}$$

The desired signal power will first be assumed to be high or $(S/N)_I = 25$ dB.

$$(S/\hat{I})_I = (S/N)_I - (\hat{I}/N)_I$$

$$= 25-60$$

$$(S/\hat{I})_I = -35 \text{ dB}$$

From the degradation curve for $(S/N)_I = 25$ dB (Figure III-38) it is found that AI = 0.76 for an $(S/\hat{I})_I = -35$ dB. This value is just above the minimum performance level for pulsed interference (AI = 0.7).

If the desired signal power is low, $(S/N)_I = 10$ dB, then

$$(S/\hat{I})_I = 10-60$$

$$(S/I)_I = -50 \text{ dB}$$

For the value of $(S/\hat{I})_I = -50$ dB, using the $(S/N)_I = 10$ dB curve in Figure III-38, the AI = 0.36. This is unacceptable performance for a voice system with pulsed interference. If the $(S/\hat{I})_I$ were increased to -30 dB (See Figure III-38) the AI would be 0.7 for the low signal curve [$(S/N)_I = 10$ dB]. The 20 dB reduction in interference could be accomplished by off-tuning the A3J receiver approximately 0.65 MHz from the radar tuned frequency (assuming 20 dB/decade spectral fall-off for the pulsed emission).

As a result of this simplified analysis one could say that the receiver could operate with performance above the minimum (AI = 0.7) for a high signal level. Under low signal level conditions the receiver could maintain a minimum performance level except when tuned closer than 0.65 MHz to the interfering radar carrier.

APPENDIX I

DEGRADATION MEASURES

GENERAL

The following is a discussion of how the baseband output (desired and undesired signals) is measured to evaluate performance degradation of voice and digital systems. Reference 9 contains a general discussion of this topic.

The "complete" mathematical modeling of a system's performance is the end objective of a prediction analysis. However, there does not exist one complete mathematical operation for analyzing all types of system performances and the best that can be accomplished is to use the measures that are most appropriate to a particular system (i.e., mean square measures, probability measures, etc.). The basic difficulty is to determine what exact type of evaluation should be associated with interference degradation. Although considerable research has been conducted on performance degradation evaluation, the desired outputs for receiving systems still reduce to a few basic types. In particular, for voice systems, Articulation Score (the percent of words correctly received) is still used as the main intelligibility standard. For digital systems, the probability of detection and probability of false alarm are desired. For analog signals, the mean square error (or the RMS error) is usually desired.

The following discussion will examine the performance measures of articulation score, articulation index, CORODIM and minimum interference thresholds for voice systems. Performance degradation of digital systems will be examined in terms of error probabilities. Analog system performance is described by the mean square measures.

ARTICULATION SCORE

The basic measure of the intelligibility of a voice system is in terms of the percent of words correctly understood over a channel perturbed by interference. This intelligibility indication has been designated as an articulation score (AS) and its measurement is usually conducted with specific types of words or syllables as well as specific system parameters. In an attempt to define the main voice parameters that are involved, experiments have been conducted by varying (at audio frequencies) the word content, bandwidth, audio (S/N) and the type of talkers and listeners that are involved. Through these experiments, articulation scores have been obtained as functions of the above variables and, as one would expect, the scores increased with increasing bandwidth, number of syllables in the

words, speaker-listener familiarity, and audio (S/N).

If the receiving system is subjected to a range of distortion or masking conditions, the AS may then be determined as a function of the interfering condition. Figure I-1 presents typical AS curves for different phonetically balanced (PB) word groupings in which the interference was white noise of various bandwidths (Reference 10). White noise, which contains a continuous uniform spectrum, is one of the most effective maskers of speech and is often used in speech intelligibility studies as a standard or reference interference.

The articulation testing procedure is not simple nor has it always been standardized. Because it deals with the performance of human beings, the tests can yield variable results in individual cases when proper statistical safeguards are not taken. It is generally necessary to use a number of listeners in order to obtain statistically meaningful results. Proper conduct of the test is tedious and time consuming. The situation is aggravated by the necessity for training the listeners to an efficiency level where the improvement resulting from repeated exposure to most word lists no longer occurs. The test procedures, the material used, and the techniques employed to measure the average power of the desired and undesired signals vary among investigators.

In spite of such shortcomings, the tests provide the most valid objective method available for evaluating the intelligibility of speech communication components or systems. When the AS tests are carefully organized, the scores are repeatable 68% of the time within a 2 dB data spread.

The AS test was used as the basic standard of intelligibility for this study. However, since this method cannot be mechanized, it is advantageous to use other techniques that allow machine computation. A number of these techniques will be subsequently discussed.

ARTICULATION INDEX

There are a number of approaches that provide a measure of the effects of undesired signals on speech communications systems by calculation and/or instrumentation of a criterion measure in each of a number of bands in the speech frequency spectrum. The articulation index (AI) approach is relatively well-known. Others are the formant intelligibility and pattern correspondence index (PCI) approaches.

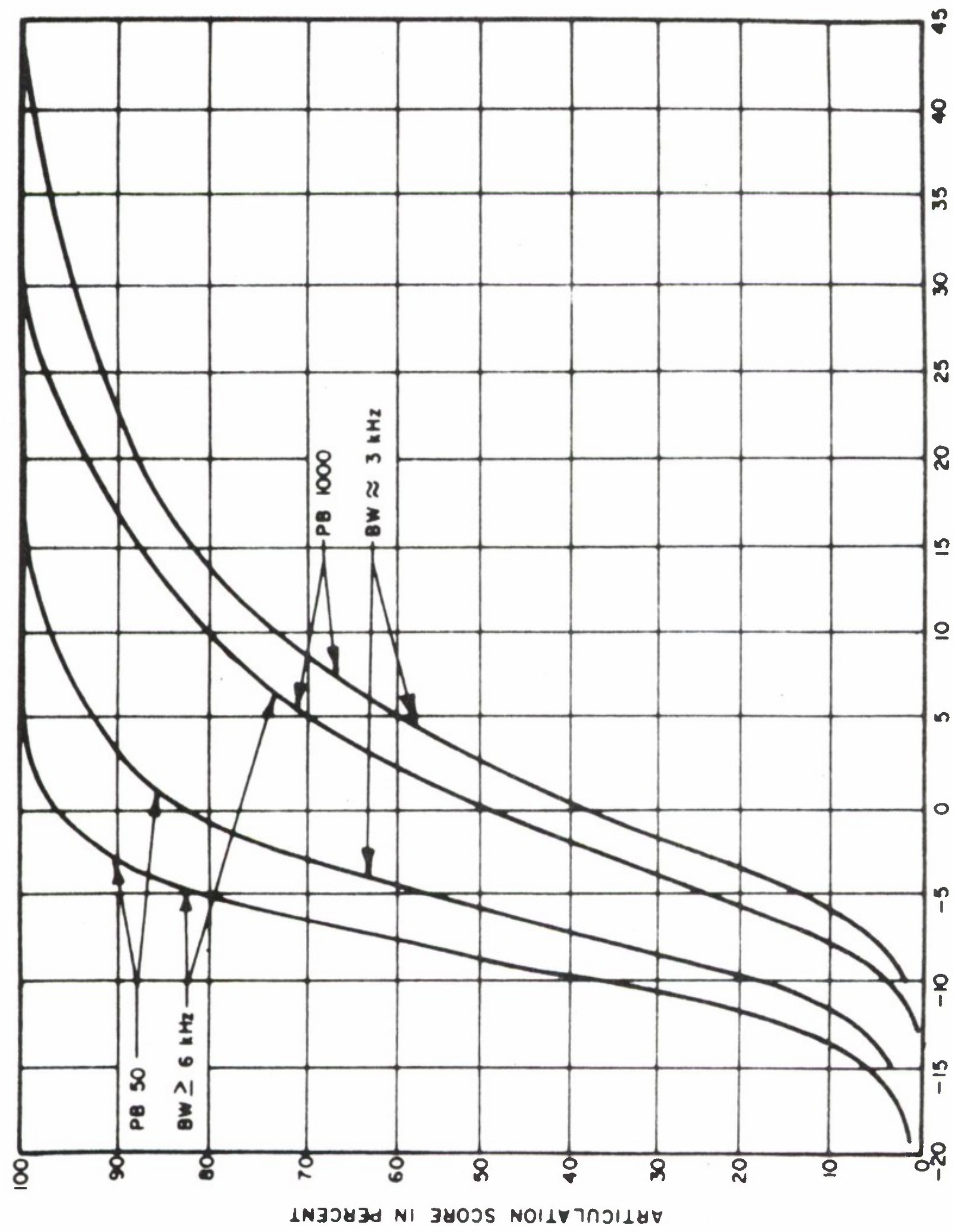


Figure I-1. Articulation Score versus Noise Interference

All these methods operate on the short-term power spectrum to obtain a performance measure of speech. Basically, the procedures stem from the original work of French and Steinburg that led to the concept of articulation index (AI) (Reference 11). That effort, essentially, determined that one can divide the speech spectrum into N unequal contiguous bands which contribute equally to intelligibility (in terms of AS). The method ideally assumes there are negligible effects on intelligibility due to the speech sounds from one band masking, or in some way affecting, sound components of another band. Effects of noise and other factors (interference, distortion) prevent these bands from making their full contribution to intelligibility. The intensity of speech varies according to the band. For these and other reasons, a weighting factor must be included for each band in recognition of the fact that some bands do not make the maximum possible contribution to speech intelligibility. The weighting factors vary for each band according to the ratio of the speech energy (in that band) to the hearing threshold. When the speech energy level in the band is 30 dB or more above the threshold level, it contributes its maximum value and hence has a unit weighting factor. When the speech energy level is between 0 and 30 dB above the threshold, the band's contribution is proportional to its energy level, in dB. When the energy level is below the threshold there is no contribution to intelligibility and the weighting factor vanishes. These weighting factors are additive and the sum can be used with empirical curves to determine the corresponding articulation score.

The French and Steinburg method is, however, still fairly complex and simpler methods have been developed. Another procedure, the tonal method, asserts that the intelligibility of speech depends, not on the absolute magnitude of speech and undesired signal intensities, but rather on the amount by which the speech exceeds the auditory threshold level for a particular type of noise. This perception level is determined in each of 20 equally contributing bands covering 100 to 10,000 Hz for standardized speech and for particular undesired signals. The tonal method, "formant intelligibility" (Reference 12) has the property of additivity such that the overall intelligibility is the sum of the contributions from each band.

The formant intelligibility process is readily automated by feeding pure tones from an artificial voice source, one at a time, to each of the n channels. Listeners then measure the excess noise in each band by attenuating the standard test signal until it is barely audible. The formant intelligibility can then be related to syllabic intelligibility by empirically obtained curves. The importance of this method is that it eliminates most of the variabilities associated with the transmission process and eliminates the AS scoring procedure. It does not, however, eliminate the listener as the end subjective evaluator.

Other methods have been developed which measure the effects of the undesired signals without subjective listener evaluation. Two of these have led to the development of testing machines by General Electronics Labs (GEL), based upon the assumption that speech intelligibility resides principally in the short term spectrum.

One machine measures a number called the pattern correspondence index (PCI) (Reference 13). This number is an index of the correlation between a speech spectrum without interference and the same speech pattern with interference. The PCI is actually obtained by taking the average spectral difference between recorded sentences without interference and the transmitted sentences with interference. The PCl, theoretically, has a monotonic relationship to articulation score and should be calibrated for white noise interference. It is postulated that the curve for white noise is universally applicable as a function of signal-to-noise, independent of the type of interference. If AS versus noise curves are available for the particular undesired signal case being investigated, a direct translation between PCl and AS can be made. This machine uses an autocorrelation measure of the desired signal and the corrupted output. Therefore, except for possible mechanical deficiencies, this approach is adequate or indequate depending on the effectivness of the autocorrelation measure for the particular interference being considered.

The other machine, produced by GEL to measure voice intelligibility mechanically, is called the Voice Intelligibility Analysis Set (VIAS) (References 14 and 15). This device also operates on the principle, previously described, of dividing the spectrum into a number of unequal continuous bandwidths (14) and measuring the desired-to-undesired signal ratio relative to the hearing threshold. The width of each band is selected such that all bands contribute equally to intelligibility. The sum of the contributions from each band is then averaged over all 14 bands to produce the composite AI. The 14 VIAS frequency bands are shown in Figure I-2 and the calculation of AI is depicted graphically in Figure I-3. In order to perform this basic calculation, a synthetic desired speech signal, which consists of a triangle-modulated 950 cycle tone, is transmitted over the test channel and is then measured by the recording portion of the device, in order to determine representative speech levels in the 14 bands. The average power (over a 17 sec. period) of the undesired signal in the 14 bands is then measured and from knowledge of the average desired signal in that band, the desired-to-undesired signal ratio is computed. The articulation index is then computed by summing the contribution from each of the 14 bands. VIAS incorporates empirically-derived correction factors to account for the upward spread of masking. This is the phenomenon in which interference at a low frequency masks a higher frequency portion of the voice spectrum. A correction must also be inserted manually for the receiver's frequency characteristics, which are

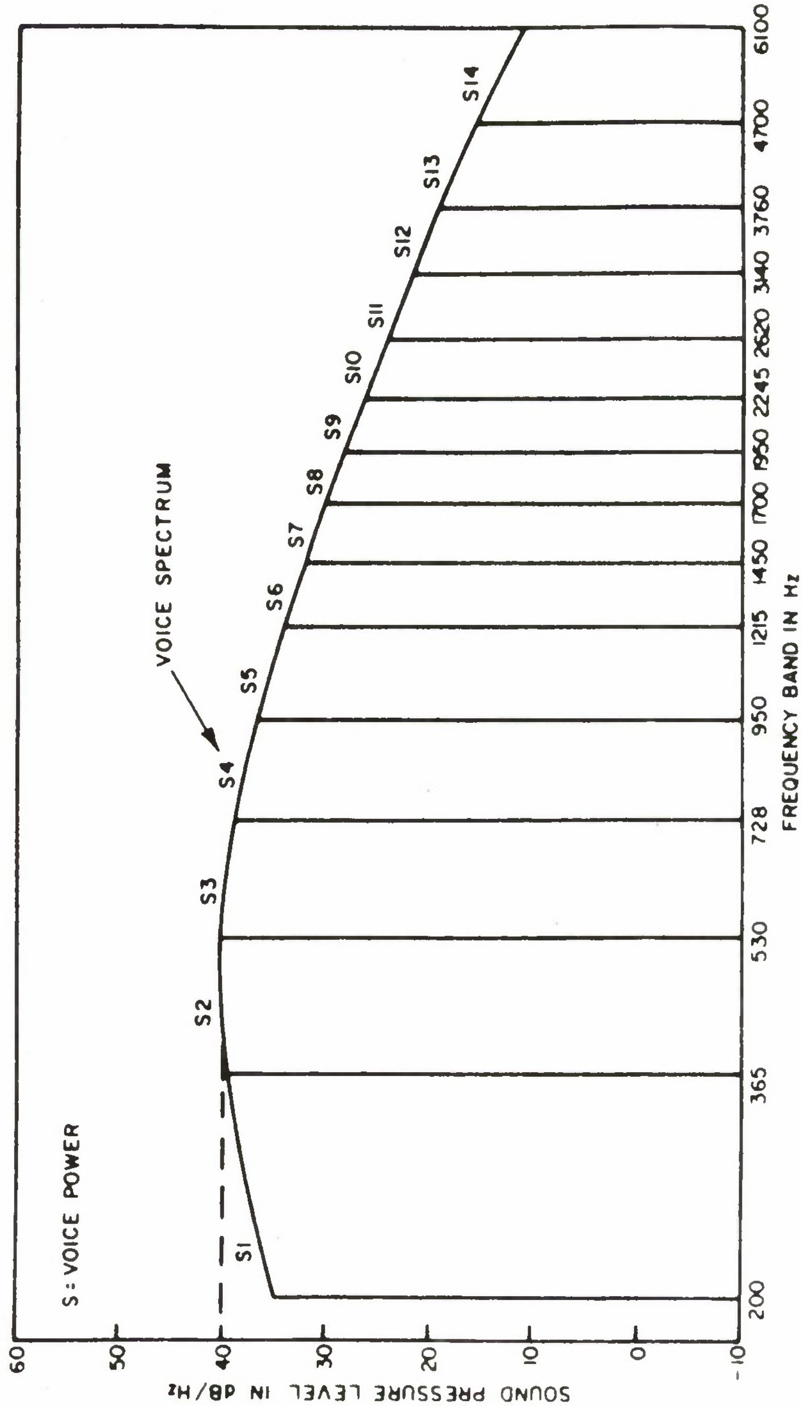
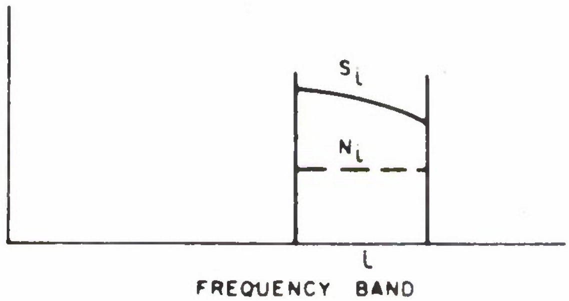
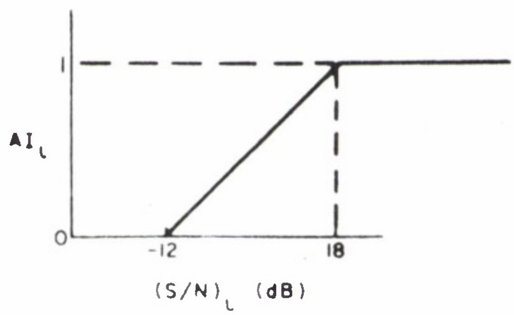


Figure I-2. Long Term Speech Spectrum and Associated AI Bands



$$AI = \frac{\sum_{i=1}^{14} (AI)_i}{14}$$



$$(S/N)_i = 10 \text{ LOG}_{10} \frac{S_i}{N_i}$$

Figure I-3. Theoretical Calculation of AI Score

determined by measurement of the system. Reference 14 discusses this correction factor in detail. The important difference between the AI machines and the tonal method is the simplification to one test signal and the elimination of the subjective evaluation. The VIAS method implies that interfering effects are independent and, consequently, additive. This last statement is especially critical since the use of a number based on this technique, even for the simplest use (i.e., that of system comparison and not performance measurement), requires validation for situations in which the noise is not additive.

Another device that automatically calculates the AI, in a slightly different manner, is the Speech Communications Index Meter (SCIM) produced by Bolt, Beranek and Newman, Inc. (Reference 16). The basic difference between this device and VIAS is the manner in which the synthetic voice signal is generated. In the SCIM machine, a noise spectrum is transmitted that has been frequency-filtered or shaped to correspond to the average voice spectrum. This signal is then filtered into nine frequency bands and used to compute the desired-to-undesired signal ratios. Ideally, therefore, this system has an advantage over VIAS in that the actual synthetic signal power in band N is used rather than an extrapolation of that signal. The SCIM machine also takes into account the upward spread of the masking effect.

A new version of the automated AI calculator is the PSI/COMP machine. The performance of this machine should be very similar to the SCIM machine, since it employs the same basic signal processing.

Degradation measurements involving a large number of parameter variations (PW, PRF, etc.) were desired for this investigation. Because of the time required to run AS tests with all these parameter variations, it was desired to use an automated measure. The VIAS AI scoring machine was chosen for these measurements because preliminary investigation had shown that the PSI/COMP machine (and probably SCIM, since they are very similar) did not appear to respond correctly to pulsed interference.

Another concept, called CORODIM (Correlation of the Recognition of Degradation with Intelligibility Measurements), has recently been developed (Reference 17). This technique is similar to the previous methods in that the baseband power spectrum is again used as a basic measure. It differs from other automatic intelligibility measuring techniques in that it transmits a test signal composed of speech-like sounds representative of phonemic consonants. The degradation manifests itself as an "effective noise spectrum" which is measured and matched to one of a library of reference noise spectra. For each reference spectrum, data are stored relating phonemic recognition probability to speech-to-noise ratio. Thus, by means of the spectrum matching operation and a measurement of signal-to-noise

ratio, each component sound of the test signal is assigned a probability of recognition. These values are weighted by phoneme probability of occurrence factors, summed and normalized to obtain a score representative of word intelligibility based on either initial or final consonant recognition. CORODIM evaluates scores for both the initial and final consonants and takes their product for the overall word intelligibility score.

The scores obtainable for CORODIM are directly comparable to listner panels according to Philco, the developer. If sufficient audio spectra have been pretested, the AS results from CORODIM should also be valid for most (but not necessarily all) interfering signals. This technique, therefore, has an important theoretical advantage over all previous automated scoring techniques.

CORODIM was not used in this investigation. It has been discussed because of its potential use in future voice degradation problems. In particular, it should be apparent that it is only necessary to couple the CORODIM process with the simulated receiver output to obtain simulated AS scores.

MINIMUM INTERFERENCE THRESHOLDS

A degradation threshold level is by implication the level at which the interference is first observed. For the audio case being considered, the minimum interference threshold is the level at which the interference is first heard. Since this level is obtained through a subjective evaluation there is an inherent variability due to the human observer and also one due to the manner in which the threshold is defined to the observer. In particular, the threshold level can be determined by decreasing or increasing the interference level relative to a fixed desired signal level. In the first case the test begins with very noticeable interference and stops when the interference is just perceptible. In the second case the interference is increased until the subject records that the interference was first heard. The first method is more repeatable than the second, although care must be taken to insure that the level recorded is indeed the last level that can be heard. This is easily implemented by allowing the subject to adjust the interference level above and below the threshold level to definitely determine that the interference was or was not heard.

The test can also be made without the presence of a desired signal. This type of test would be used for high fidelity, TV, or stereo systems where the presence of interference during the time the desired signal intelligence is absent may be unacceptable. A lower threshold interference level would be required for this case than if the desired signal were present, since the desired signal aids in masking the presence of the interference.

The validity of this type of measurement is shown in Reference 12. Two separate listening crews were used to determine the threshold of perceptibility (minimum interference threshold) for speech masked by noise. One crew contained three experienced listeners and the other contained eight inexperienced listeners. The signal (speech)-to-noise ratio (S/N) was then adjusted by each listener until he obtained the threshold of perceptibility. With the exception of one individual in the crew of eight, the maximum variation in the S/N ratio required by each listener was 3 dB. The average difference in S/N between the two crews was less than 1 dB.

ERROR PROBABILITIES

The evaluation of digital performance measures basically consists of computing error probabilities. In a general sense this consists of evaluating the categories of false acceptance and false dismissal. In the simplest type of detection problem (single alternative decision), false acceptance is equal to the probability of false alarm while that of false dismissal is equal to the quantity one minus the probability of detection. These can be considered by simply examining the probability densities for noise alone and for signal and noise at the receiver output (see Figure I-4). In this figure $Q_n(x)$ refers to output noise distribution density while $P_n(x)$ is the output distribution density when signal, noise and interference are present. The false alarm probability α is the area of $Q_n(x)$ above the decision threshold K. The area of $P_n(x)$ above the threshold K is the probability of detection. One minus this value or the area of $P_n(x)$ below the threshold K is the false dismissal probability β. These quantities can be stated mathematically as

$$\alpha = \int_K^\infty Q_n(x)\, dx$$

$$\beta = \int_{-\infty}^K P_n(x)\, dx$$

Both $P_n(x)$ and $Q_n(x)$ are output probability densities obtained by operating on the input probability densities with the receiver system structure. If, as an example, the receiver has an envelope detection-threshold type of structure the envelope of the input probability density distribution must be obtained in order to obtain $P_n(x)$ or $Q_n(x)$ before the false acceptance or false dismissal probabilities can be calculated. This operation is, in general, nonlinear.

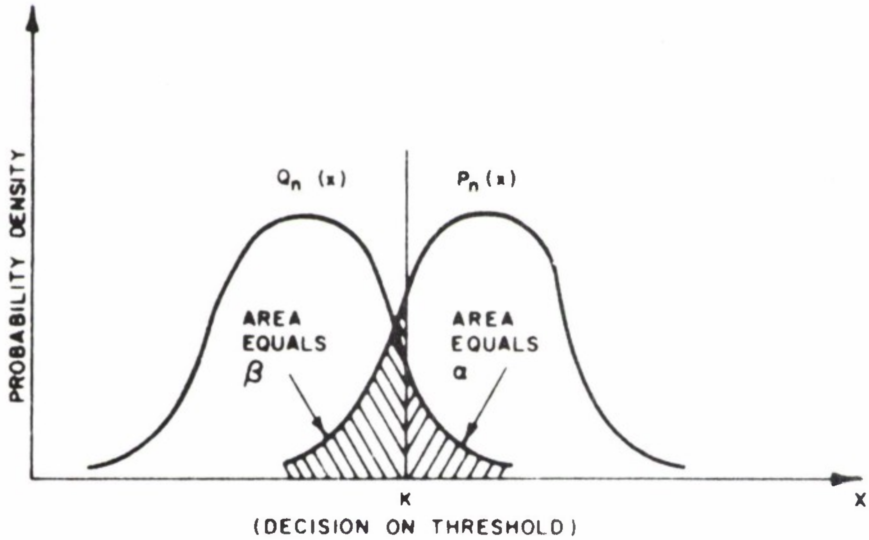


Figure 1-4. System Probability Density With Decision Regions

The calculation of $Q_n(x)$ and $P_n(x)$ for specific a priori interference and noise assumptions generally involves untractable analysis problems. However, the modeling of the receiver structure and the simulation process readily allow error probability evaluation. In particular, it is basically only necessary to count the number of undesired responses above a desired threshold (K) in the simulated receiver time amplitude output response to obtain false alarm probabilities. It is, of course, also necessary to properly randomize the input variables to obtain the desired output density function for these calculations. The false dismissal probabilities can also be obtained in a similar manner.

MEAN SQUARE ERROR

In digital or discrete communication systems it is meaningful to measure the system performance in terms of the probability of error. In the case of an analog or continuous modulation system the transmitted and received messages are in general different because of small interference or noise perturbations. The probability of error would be unity in most situations and is a useless indicator of the performance of an analog system.

The classical approach is to assume that fidelity of waveform reproduction is the communication objective of an analog system. The criterion of goodness for an analog communication systems disturbed by white Gaussian noise has become the mean square error between the input and output waveform. For the single random variable communication system of Figure I-5, the mean square error is defined by the equation (Reference 19):

$$\overline{\varepsilon^2} \triangleq E[(m-\hat{m})^2] = \overline{(m-\hat{m})^2}$$

where:

$E[(m-\hat{m})^2]$ = expected value

$\overline{\varepsilon^2}$ = mean square error

m = transmitted message

$\hat{m}$ = received message

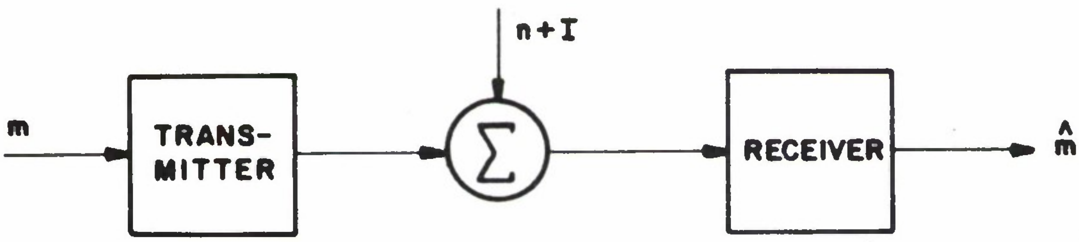


Figure I-5. Single Random Variable Communication System

APPENDIX II

DESIRED AND INTERFERENCE MODULATION DESCRIPTION AND RECEIVER CHARACTERISTICS

The performance degradation curves included in the Degradation Handbook are grouped by desired-to-interference modulation categories. The desired modulation types consist of A2, A3, A3J, A9B, F1, F3, F9 and the interference modulation types consist of A1, A3, A3J, A9B, F1, F3, F9, PO and Noise. This section of the report contains a description of the signal and receiver parameters needed for the analysis. These parameters are representative of those contained in MIL-STD-188C, CCIR reports, and Reference 22. Each desired signal category consists of a description of the modulation type and the receiver for that type of modulation. The desired signal and receiver parameters used to generate the degradation curves are listed in the specifications. The interference signal description is included in the Interference Signal Specification subsection when the interference signal description is not the same as the desired signal description. The parameters of the interference signals are listed under the Interference Signal Specifications.

DESIRED SIGNAL AND RECEIVER DESCRIPTION

A2 Digital Receiver and Signal Description

A2 modulation is described by standard codes for modulation types (Reference 22) as "Telegraphy by the on-off keying of an amplitude modulating audio frequency or audio frequencies, or by the on-off keying of the modulated emission (special case: an unkeyed emission amplitude modulated)".

The A2 modulation described in this handbook is simulated by amplitude modulating a continuous wave carrier 100% with two tone frequencies. This approximates the condition where each modulating tone is on 50% of the time (i.e., each binary state is equally probable).

Figure II-1 shows the block diagram of a typical A2 receiver that is analyzed to solve cochannel interference problems. The IF adjacent channel interference case is eliminated for narrowband interference signals by the sharp filter characteristics. The wideband IF adjacent interference signal case is discussed in Section 3. The analysis considers audio filtering, discriminator baseband filtering, and bit error probability degradation criteria. The bit error probability is obtained by applying the output (S/I) power ratio at the low pass filter (Reference 6)

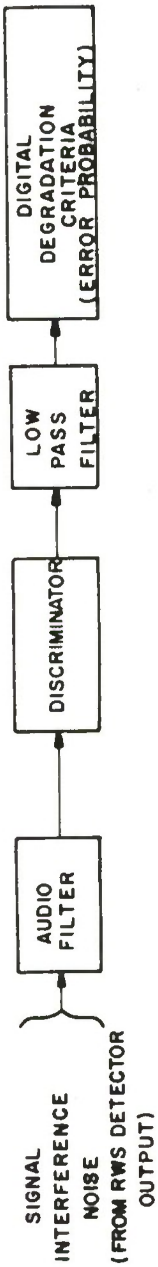


Figure II-1. A2 Receiver Analysis Structure

in Equation (7-77) from Reference 20. The difference between the interference signals analyzed and white noise interference in the discriminator output had little effect on the bit error probability.

Desired Signal and Receiver Specifications

The following are the desired signal and receiver parameters used in the A2 analysis.

1. Bit rate 100 Bauds (bits/sec)
2. Baseband filter 100 Hz
3. Deviation ±425 Hz
4. Audio filter 3 kHz

A3 (AM) Voice Receiver and Desired Signal Descriptions

The A3 modulation category describes the transmission of voice information by amplitude modulating a continuous wave carrier. Reference 22 describes A3 modulation as "Double-Sideband Telephony". A voice signal modulates a carrier at a peak modulation level of 100%. This corresponds to a rms modulation level of approximately 30%. The voice baseband of commercial or military equipments is specified as extending from 0.3 to 3.5 kHz.

The typical block diagram of the receiver structure that is analyzed in order to solve cochannel and adjacent signal interference problems is shown in Figure II-2. The analysis considers IF filtering, nonlinear envelope detection, baseband filtering, nonlinear AGC desensitization and articulation index (AI) or articulation scoring (AS) degradation criteria. The structure shown in this diagram is used for the analysis of interfering signals that are off-tuned as far as the 80 dB IF rejection level.

Desired Signal and Receiver Specifications

The following are the specifications of desired signal and receiver parameters used in the analysis.

1. Audio bandwidth of 0.3 to 3.5 kHz (six low and six high pass stages).
2. IF bandwidth of 8 kHz (five double tuned stages).
3. Modulation index of 30% (m_s = 0.3).
4. Harvard phonetically balanced (PB) 1,000 word vocabulary used in articulation scoring (AS) criteria (fatigue factors and hard clipping are not considered).

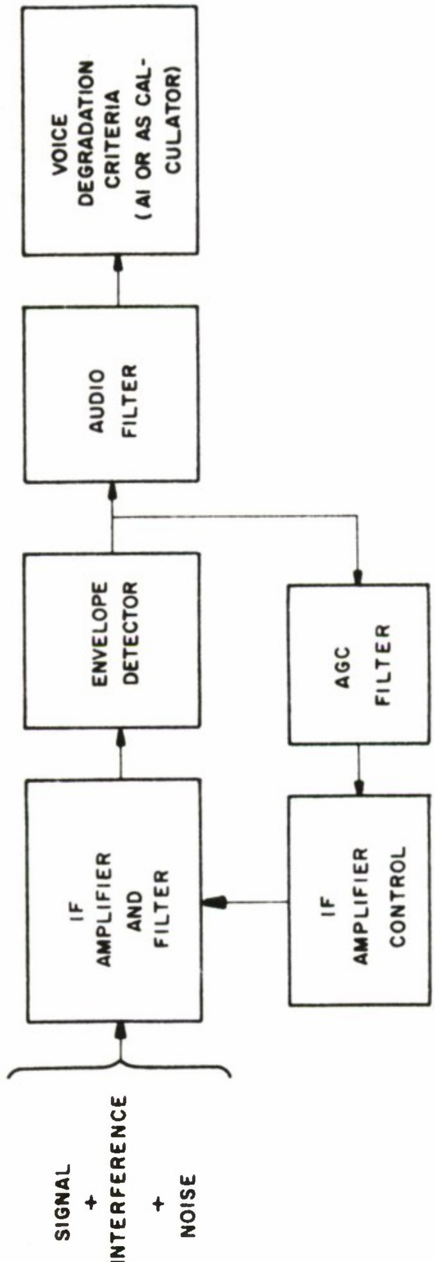


Figure II-2. AM Receiver Analysis Structure

A3J (Single Sideband) Voice Receiver and Desired Signal Descriptions

The A3J modulation category describes the transmission of voice information by amplitude modulation with suppression of the continuous wave carrier and lower sideband. The voice baseband bandwidth of commercial or military equipments is specified as extending from 0.3 to 3.0 kHz.

The block diagram of the typical receiver structure that is analyzed to solve cochannel problems is shown in Figure II-3. The IF adjacent signal interference case is eliminated for narrowband interference signals by sharp IF filter characteristics. The wideband IF adjacent signal interference case is discussed in Section 3. The analysis considers IF filtering, ideal product detection, audio filtering, and articulation index (AI) or articulation scoring (AS) degradation criteria.

Desired Signal and Receiver Specifications

The following are the specifications of desired signal and receiver parameters used in the analysis.

1. Audio bandwidth of 0.3 to 3.0 kHz (six low and six high pass stages).
2. IF bandwidth of 2.7 kHz (ten double tuned stages).
3. Harvard phonetically balanced (PB) 1,000 word vocabulary used in articulation scoring (AS) criteria (fatigue factors and hard clipping are not considered).

A9B Voice Receiver and Desired Signal Descriptions

A9B describes a broad category of amplitude modulation. To obtain a representative case of A9B transmission, the C&E Directory (Reference 21) was reviewed to obtain a list of equipments with A9B modulation. Technicalmanuals for these equipments were searched for descriptions of the modulations used. The most representative type of A9B modulation was found to be four channel voice composite transmission.

This type is described as four independent voice channels single sideband modulated so as to be spaced one adjacent to the other symmetrically around a continuous wave carrier. At the receiver the IF filter eliminates the two sidebands above the carrier or the two below. The two remaining channels are then envelope detected about the carrier frequency. The upper sideband is removed by a low pass filter if the lower channel is desired. If the upper channel is desired a product detector shifts it to baseband.

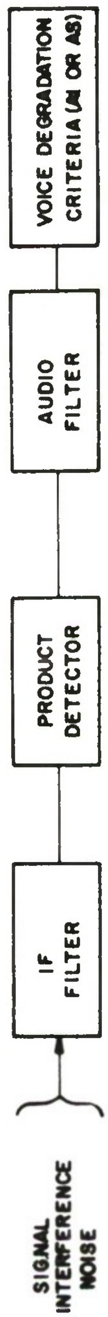


Figure II-3. A3J Receiver Analysis Structure

The block diagram of the receiver structure that is analyzed to solve cochannel problems is shown in Figure II-4. The IF adjacent signal interference case is excluded for narrowband interference signals because the sharp IF filter characteristics eliminate the possibility of this condition occurring. The wideband IF adjacent signal interference case is discussed in Section 3.

Desired Signal and Receiver Specifications

The following are the specifications of desired signal and receiver parameters used in the analysis.

1. Audio bandwidth of 0.3 to 3.5 kHz (six low and six high pass stages).
2. IF bandwidth of 16 kHz (ten double tuned stages).
3. Harvard phonetically balanced (PB) 1,000 word vocabulary used in articulation scoring (AS) criteria (fatigue factors and hard clipping are not considered).

F1 (Frequency Shift Key, FSK) Digital Receiver and Signal Descriptions

The standard codes for modulation types (Reference 22) describes the F1 category as "telegraphy by frequency shift keying without the use of a modulating audio frequency, one of two frequencies being emitted at any instant". Binary frequency shift key modulation is a continuous wave carrier which shifts from one frequency to another, each channel frequency representing a mark or space of binary coded information.

The FSK modulation is simulated by a continuous wave carrier frequency modulated by a tone frequency. The peak-to-peak frequency deviation of the carrier approximates the channel separation of the FSK signal. The tone modulating signal approximates a 50% duty cycle rectangular pulse train (i.e., a binary signal where a mark or space is equally probable).

Figure II-5 shows the block diagram of a typical low speed F1 receiver that is analyzed to solve cochannel interference problems. The IF adjacent signal interference case is eliminated for narrowband interference signals by the sharp IF filter characteristics. The wideband IF adjacent signal case is discussed in Section 3. The analysis considers IF filtering, ideal limiting, discriminator detection, baseband filtering and a bit error probability degradation criteria. The bit error probability is obtained by applying the output S/I power ratio at the low pass filter (Reference 6) in Equation (7-77) of Reference 20. The difference between the interference signals analyzed and noise interference in the discriminator output had little effect on the bit error probability.

Figure II-4. A9B Receiver Analysis Structure

Figure II-5. F1 Receiver Analysis Structure

Desired Signal and Receiver Specifications

The following are the desired signal and receiver parameters used in the F1 analysis.

1. Bit rate 100 bauds (bits/sec)
2. Channel separation 850 Hz
3. IF bandwidth 1050 Hz
4. Baseband filter 100 Hz

F3 (FM) Voice Receiver and Desired Signal Descriptions

The F3 modulation category describes the transmission of voice information by frequency modulating a continuous wave carrier. A voice signal deviates the carrier to 5 kHz on the peaks. This corresponds to a rms deviation of 2.1 kHz. The voice baseband bandwidth of narrowband commercial and military equipments is specified as extending from 0.3 to 3.5 kHz.

The block diagram of the typical FM receiver that is analyzed to solve cochannel and adjacent signal interference problems is shown in Figure II-6. The analysis considers IF filtering, ideal limiting, discriminator detection, baseband filtering and articulation index or articulation scoring degradation criteria. The structure shown in this diagram is used in the analysis of interfering signals that are off-tuned to approximately the 80 dB IF rejection level.

Desired Signal and Receiver Specifications

The following are the desired signal and receiver parameters used in the F3 (no de-emphasis) analysis.

1. Audio bandwidth 0.3 to 3.5 kHz (six high and six low pass stages).
2. IF bandwidth of 16 kHz (four double tuned stages)
3. Peak frequency deviation of 5 kHz.
4. RMS frequency deviation of 2.1 kHz.
5. 60% modulation.
6. Harvard phonetically balanced (PB) 1,000 word vocabulary used in articulation scoring (AS) criteria (fatigue factors or hard clipping are not considered).

F3 (FM) Voice Receiver (With De-Emphasis) and Desired Signal Descriptions

F3 is the transmission of voice information by frequency modulating a continuous wave carrier. A voice signal deviates the carrier to 5 kHz on the peaks. This corresponds to a rms deviation of 2.1 kHz. The voice baseband bandwidth of narrowband commercial equipments is specified as extending from 0.3 to 3.5 kHz.

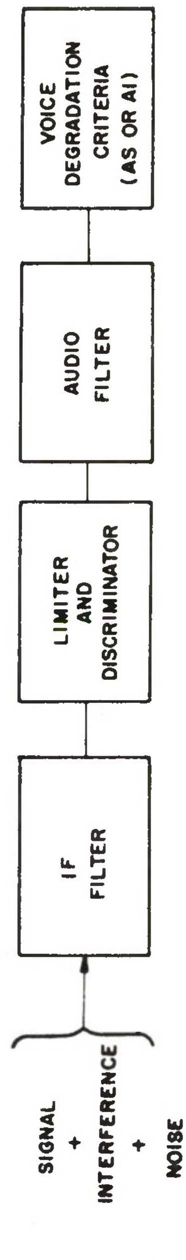


Figure II-6. FM Receiver Analysis Structure

The block diagram of the typical FM receiver (with de-emphasis) that is used to solve cochannel and adjacent signal interference problems is shown in Figure II-7. The analysis considers IF filtering, ideal limiting, discriminator detection, de-emphasis filtering, baseband filtering and articulation index or articulation scoring degradation criteria. The structure shown in this diagram is used in the analysis of interfering signals that are off-tuned to approximately the 80 dB IF rejection level.

Desired Signal and Receiver Specifications

The following are the desired signal and receiver parameters used in the F3 (de-emphasis) analysis.

1. Audio bandwidth 0.3 to 3.5 kHz (six high and six low pass stages).
2. IF bandwidth of 16 kHz (four double tuned stages)
3. Peak frequency deviation of 5 kHz.
4. RMS frequency deviation of 2.1 kHz.
5. 60% modulation.
6. De-emphasis filter - single stage low pass filter with 250 Hz break point.
7. Harvard phonetically balanced (PB) 1,000 word vocabulary used in articulation scoring (AS) criteria (fatigue factors or hard clipping is not considered).

F9 (Wideband FM Multiplex) Receiver and Desired Signal Descriptions

The F9 modulation is a non-specific category of frequency modulation. One of the most prevalent types of F9 is frequency-division-multiplex (FDM) transmission using 12 voice channels to frequency modulate a continuous wave carrier. The 12 channel baseband signal is simulated as a white noise modulated baseband. The desired channel is represented by a single audio frequency of rms level equal to the rms level of a noise loaded channel. The baseband signal is pre-emphasized and frequency modulates a continuous wave carrier which is deviated 50 kHz on the peaks (35.3 kHz rms). The bandwidth of a single voice channel is specified as extending from 0.3 to 3.5 kHz. Both a low and a high baseband frequency channel are used in the analysis.

The block diagram of the typical F9 receiver that is used to solve cochannel and adjacent signal interference problems is shown in Figure II-8. The cochannel interference condition implies the interference signal is tuned within the low or high desired channel. The analysis considers IF filtering, ideal limiting, discriminator detection, de-emphasis, demultiplexing, baseband filtering and articulation index or articulation scoring degradation criteria.

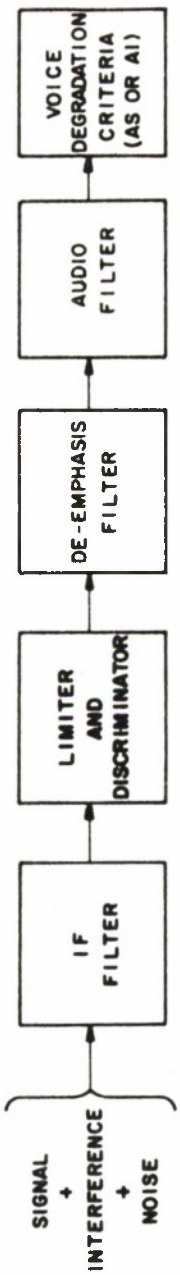


Figure II-7. FM Receiver (With De-Emphasis) Analysis Structure

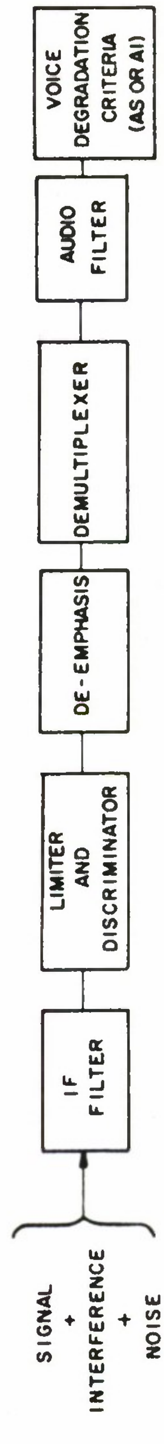


Figure II-8. F9 Receiver Analysis Structure

Desired Signal and Receiver Specifications

The following are the desired signal and receiver parameters used in the F9 desired signal analysis.

1. Baseband, 12 channels of 4 kHz white noise.
2. Desired channel occupied by only 600 Hz tone with rms power of one noise loaded channel.

   Low Channel - 4-8 kHz
   High Channel - 44-48 kHz

3. Audio bandwidth 0.3 to 3.5 kHz (six high and six low pass stages).
4. Single stage pre-emphasis filter with breakpoint frequency 3 kHz.
5. Peak deviation of 50 kHz.
6. RMS deviation of 35.3 kHz
7. Peak-to-mean power ratio of 13 dB.
8. IF bandwidth of 200 kHz (eight double-tuned stages).
9. De-emphasis, single stage with 3 kHz breakpoint frequency.
10. Harvard phonetically balanced (PB) 1,000 word vocabulary used in AS criteria (fatigue factors or hard clipping is not considered).

INTERFERENCE SIGNAL SPECIFICATIONS

A1 Digital Interference Signal Description

A1 modulation, according to the standard codes for modulation types (Reference 22), is "telegraphy without the use of a modulating audio frequency (by on-off keying)". A1 modulation is simulated by an on-off keyed (pulse modulated) continuous wave carrier. All of the A1 interference signal parameters used in measurements are not listed in the specifications.

A1 Interference Signal Specifications

1. Pulse width 10 msec,

2. Bit rate 100 bauds (bits/sec),

3. Peak interference power ($\hat{I}$) used to specify A1.

A3 (AM) Interference Signal Specifications

The following are the specifications or parameters used in the A3 interference analysis.

1. Voice bandwidth of 0.3 to 3.5 kHz.
2. Modulation index of 30% ($m_1 = 0.3$).
3. Single voice babble modulation used in AS scoring.
4. Voice-shaped noise used in AI scoring.

A3J (SSB) Interference Signal Specifications

The following are the specifications of parameters used in the A3J interference analysis.

1. Voice bandwidth of 0.3 to 3.0 kHz.
2. Single voice babble modulation used in AS scoring.
3. Voice shaped noise used in AI scoring.

A9B Interference Signal Description

The A9B interference consists of a four channel (voice) composite signal amplitude modulating a continuous wave carrier. A9B interference is simulated as 6 kHz of band limited white noise amplitude modulating a continuous wave carrier.

Interference Signal Specifications

The following are the specifications or parameters used in the A9B interference.

1. Voice bandwidth of 0.3 to 3.0 kHz.
2. Modulated RF bandwidth of 12 kHz.
3. Modulation index of 30% ($m_I = 0.3$).
4. Single voice babble modulation used in AS scoring.
5. Band limited (6 kHz) white noise used in AI scoring.

F1 Interference Signal Description

F1 Interference is simulated by a continuous wave carrier shifting between two frequencies with continuous phase between frequency transitions. Each carrier frequency is emitted 50% of the signal duration.

Interference Signal Specifications

1. Bit rate of 50 bauds (bits/sec).

2. Channel separation of 400 Hz.

3. Rectangular pulses.

F3 (FM) Interference Signal Specifications

The following are the specifications used in the F3 interference analysis.

1. Voice bandwidth of 0.3 to 3.5 kHz.
2. RMS frequency deviation of 2.1 kHz.
3. 60% modulation.
4. Single voice babble modulation used in AS scoring.
5. Voice shaped noise modulation used in AI scoring.
6. Peak frequency deviation of 5 kHz.

F9 (FDM) Interference Signal Description

The following are the specifications used in the F9 interference analysis.

1. Baseband of 48 kHz white noise.
2. No pre-emphasis.
3. RMS frequency deviation of 35.3 kHz.
4. Peak frequency deviation of 50 kHz.
5. Peak-to-mean power ratio of 13 dB.
6. Single voice babble modulation used in AS scoring.

PO (Pulse) Interference Signal Description

PO modulation is described by standard codes for modulation types (Reference 22) as "a pulsed carrier without any modulation intended to carry information (e.g., radar)". The PO interference is a continuous wave carrier modulated by a rectangular periodic pulse train.

PO Interference Signal Specifications

1. Pulse width 5 μs,
2. Pulse repetition rate 300 pulses/sec,
3. Peak interference power ($\hat{I}$) used to specify PO.

APPENDIX III

PERFORMANCE DEGRADATION CURVES

PERFORMANCE DEGRADATION CURVES

This portion of the Degradation Handbook (APPENDIX III) contains the results of the analysis described in the main body of the report. The relationship between performance degradation and input signal-to-interference power ratio are given in the form of receiver performance degradation curves. In most cases, two desired signal-to-noise ratios (a high and a low signal level) and three relative values of interference off-tuning (cochannel on-tune, cochannel off-tuned and adjacent signal) were considered for each desired-to-interference category.

The performance degradation for an AM receiver with cochannel on-tuned AM interference is shown in Figure III-1. The two curves on the figure represent a high signal level [$(S/N)_I$ = 35 dB] and a low signal level [$(S/N)_I$ = 20 dB] in the absence of an interference signal. The abscissa scale of the curve is the input signal-to-interference ratio, $(S/I)_I$, in dB. The ordinate scale indicates the performance degradation measure; in this case, the articulation score (AS) and the articulation index (AI). The minimum interference threshold, MIT, is the $(S/I)_I$ value which causes a just-perceptible interference effect. The MIT value is noted on each degradation curve for a voice modulated desired signal. The marginal performance region of each A3 to A3 curve is the region between the 0.7 AI and the 0.3 AI values. It is a region of usable but degraded performance. For $(S/I)_I$ values that lie above the partially degraded region, no interference effect is noticeable because the interfering signal is masked by normal system noise. For $(S/I)_I$ values that lie below the marginal performance region (below the 0.3 AI point), communications are not satisfactory because the receiver performance degradation process has become almost complete.

TABLE 3-4, which indicates the number of the degradation curve for each desired signal-to-interference case, has been repeated for convenience in this appendix as TABLE III-1.

TABLE III-1

LOCATION OF DEGRADATION CURVE FOR EACH DESIRED SIGNAL-TO-INTERFERENCE CASE

DESIRED \ UNDESIRED		A1	A3	A3J	A9B	F1	F3	F9	F0	NOISE
A2	On-Tune Cochannel Off-Tune Cochannel Adjacent Signal	III-2 3-1/III-2	III-3 3-2/III-3		III-4 3-2/III-4		III-5 3-1/III-5			III-6
A3	On-Tune Cochannel Off-Tune Cochannel Adjacent Signal	III-7 III-8 3-1/III-7	III-11 III-12 3-2/III-11	III-13 III-14 3-4/III-13	III-15 III-16 3-2/III-15	III-17 III-18 3-1/III-17	III-19 3-1/III-19		III-21 III-22 3-1/III-21	III-20
A3J	On-Tune Cochannel Off-Tune Cochannel Adjacent Signal	III-23 III-24 3-1/III-23	III-27 III-28	III-29 III-30 3-1/III-29	III-31 III-32 III-31	III-33 III-34 3-1/III-33	III-35	III-36	III-38 3-1/III-38	III-37
A9B	On-Tune Cochannel Off-Tune Cochannel Adjacent Signal		III-39 III-40 3-2/III-39		III-41 III-42 3-2/III-41	III-43 III-44 3-1/III-43		III-45	III-47 3-1/III-47	III-46
F1	On-Tune Cochannel Off-Tune Cochannel Adjacent Signal	III-48 3-1/III-48	III-49 3-1/III-49		III-50 3-1/III-50		III-51 3-1/III-51		III-53 3-1/III-53	III-52
F3 No De-Emphasis	On-Tune Cochannel Off-Tune Cochannel Adjacent Signal	III-54 3-3/III-54	III-55 III-56 3-3/III-55	III-57 3-3/III-57	III-58 3-3/III-58	III-59 III-60 3-1/III-59	III-61 3-1/III-61	III-62	III-64 3-1/III-64	III-63
F3 De-Emphasis	On-Tune Cochannel Off-Tune Cochannel Adjacent Signal				III-65 3-3/III-65	III-66 3-1/III-66	III-67 3-1/III-67	III-68		III-69
F9	On-Tune Cochannel Off-Tune Cochannel Adjacent Signal	III-70 III-71 3-3/III-70	III-74 III-75 3-3/III-74		III-78 III-79 3-3/III-78	III-82 III-83 3-3/III-82	III-86 III-87 3-3/III-86	III-90 III-91 3-3/III-90	III-95 III-96 3-1/III-95	III-94

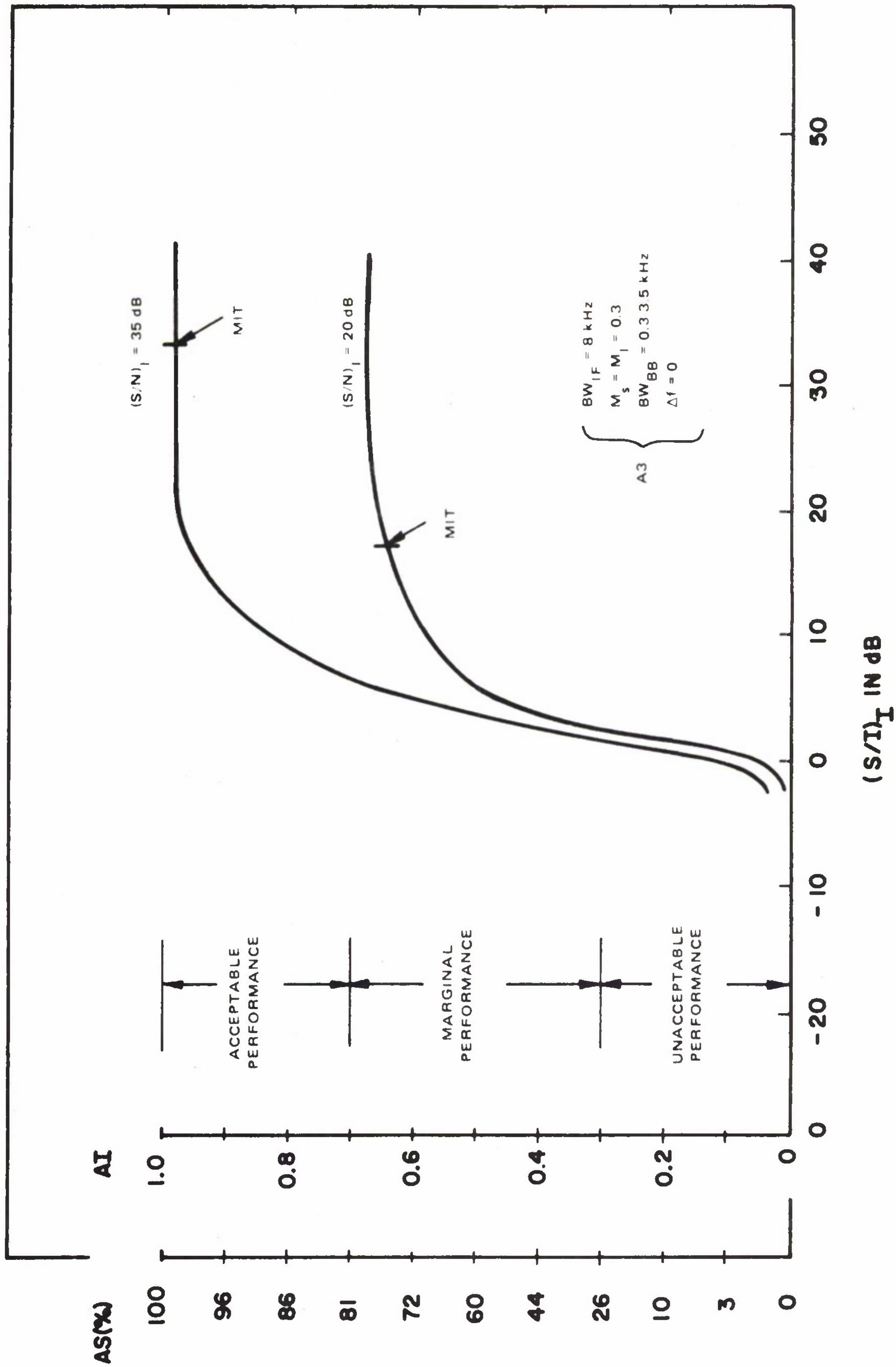


Figure III-1. Sample Performance Degradation Curve For A3 Receiver With A3 Interference ($\Delta f = 0$)

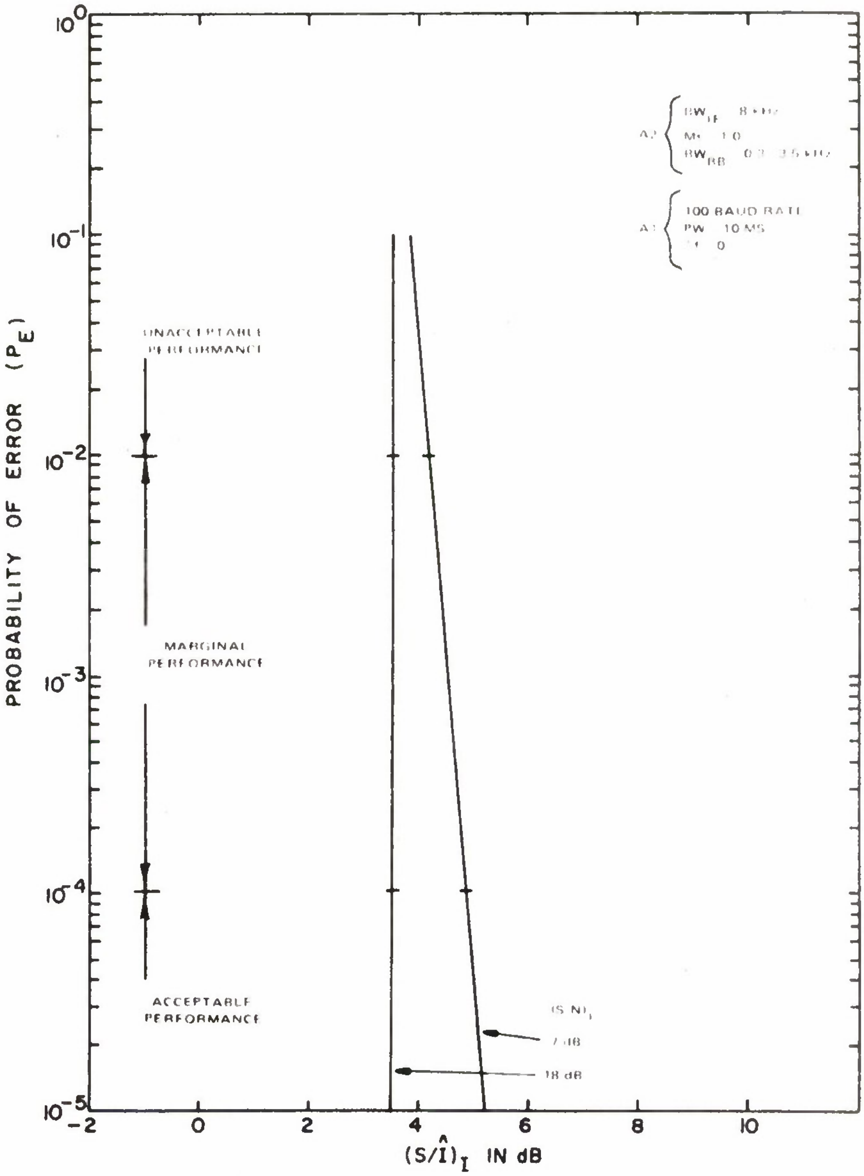


Figure III-2. Performance Degradation Curve For A2 Receiver With A1 Interference

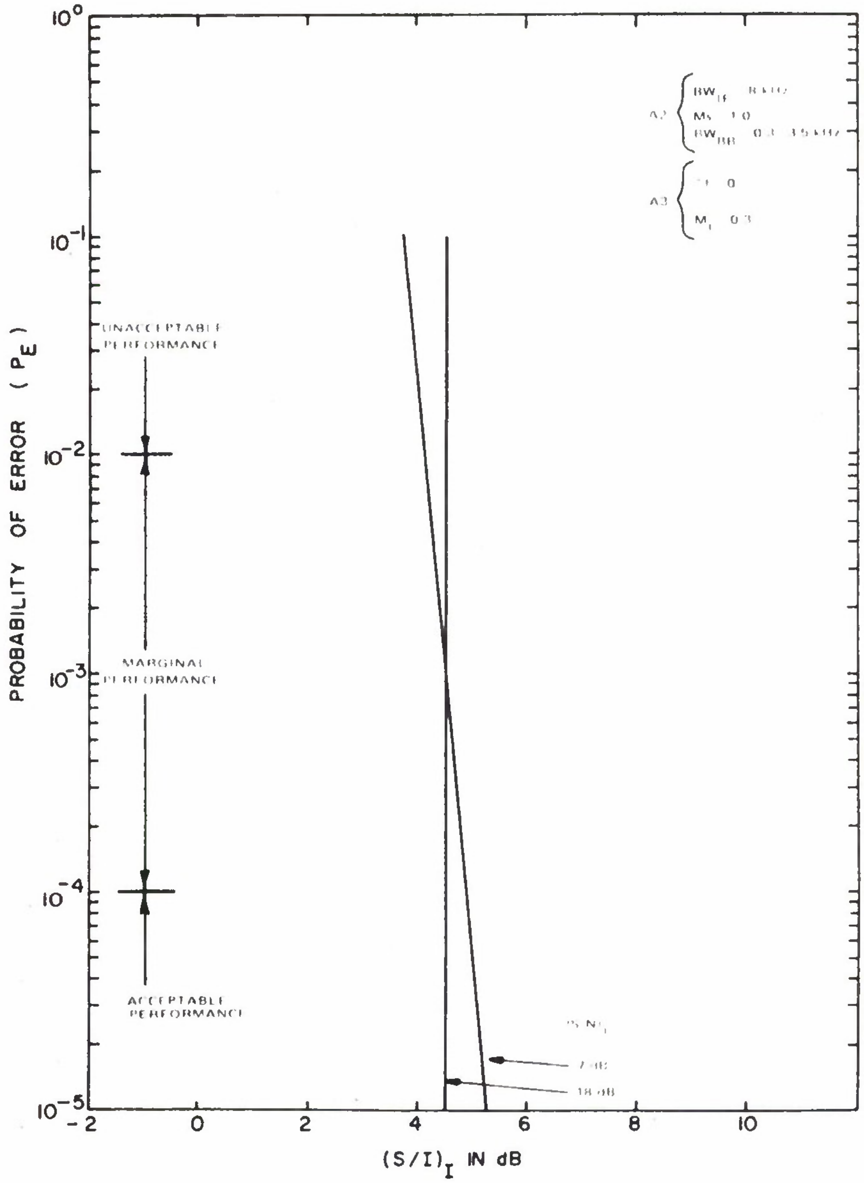


Figure III-3. Performance Degradation Curve For A2 Receiver With A3 Interference

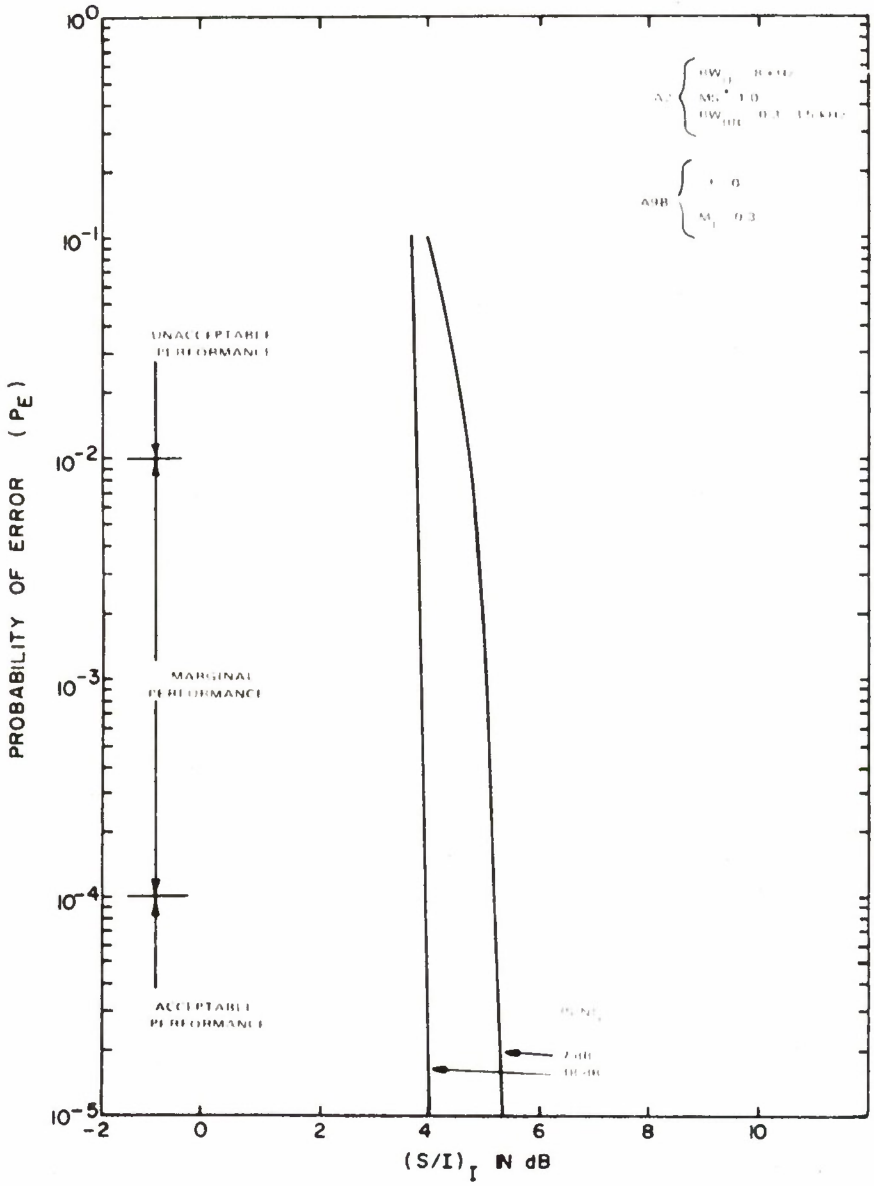


Figure III-4. Performance Degradation Curve For A2 Receiver With A9B Interference

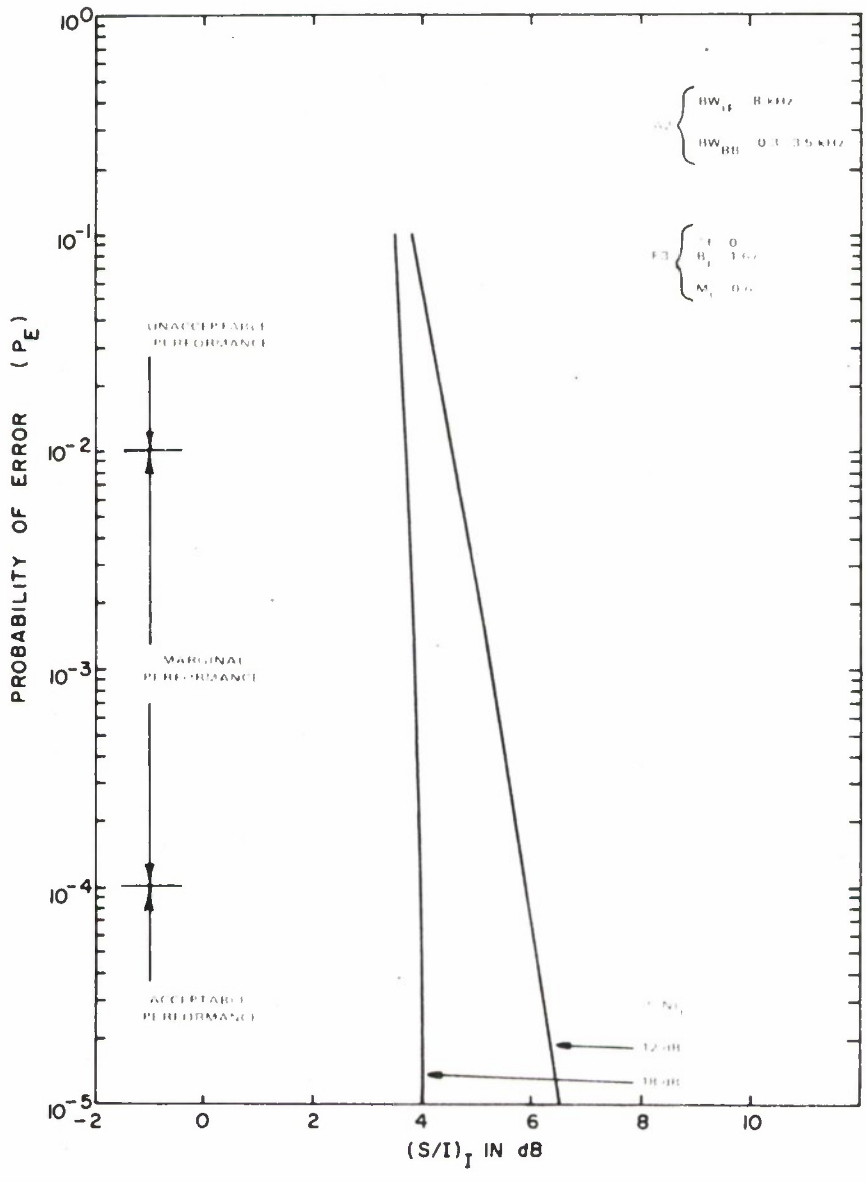


Figure III-5. Performance Degradation Curve For A2 Receiver With F3 Interference

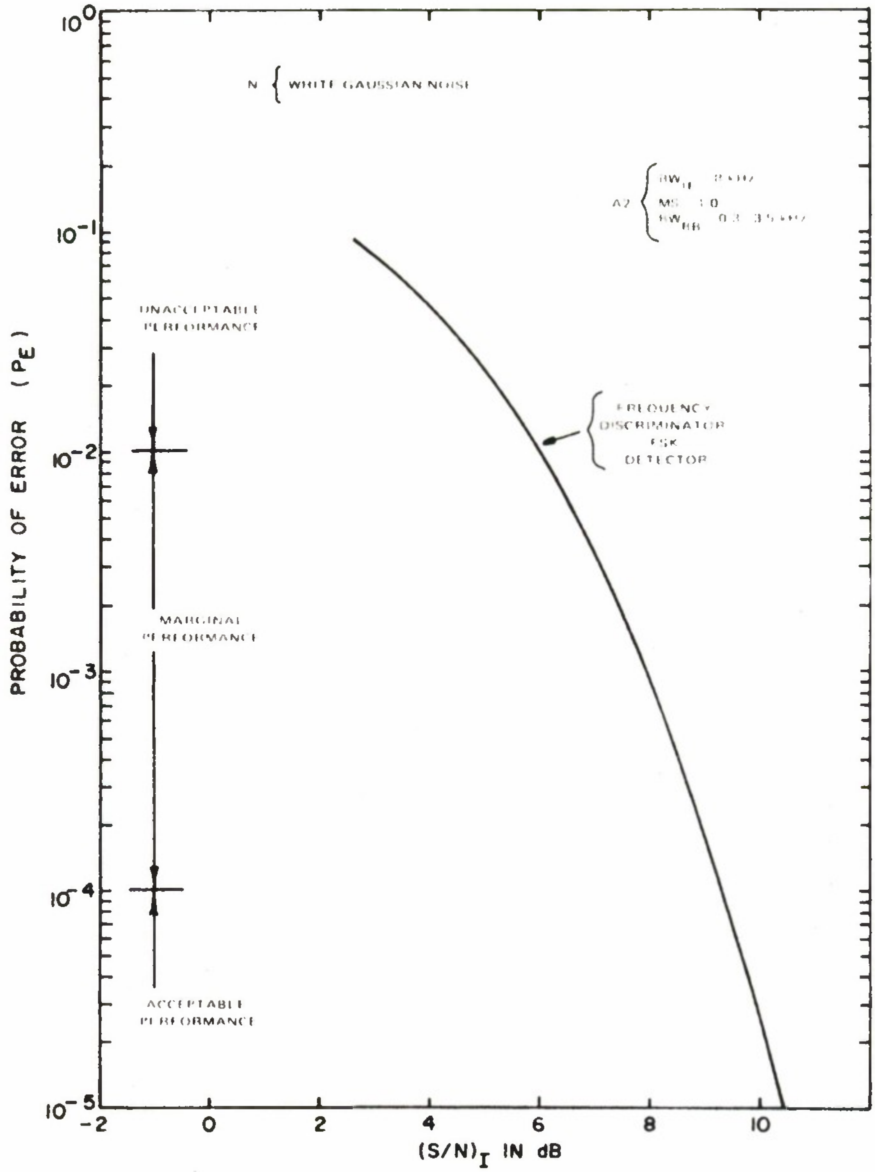


Figure III-6. Performance Degradation Curve For A2 Receiver With Noise

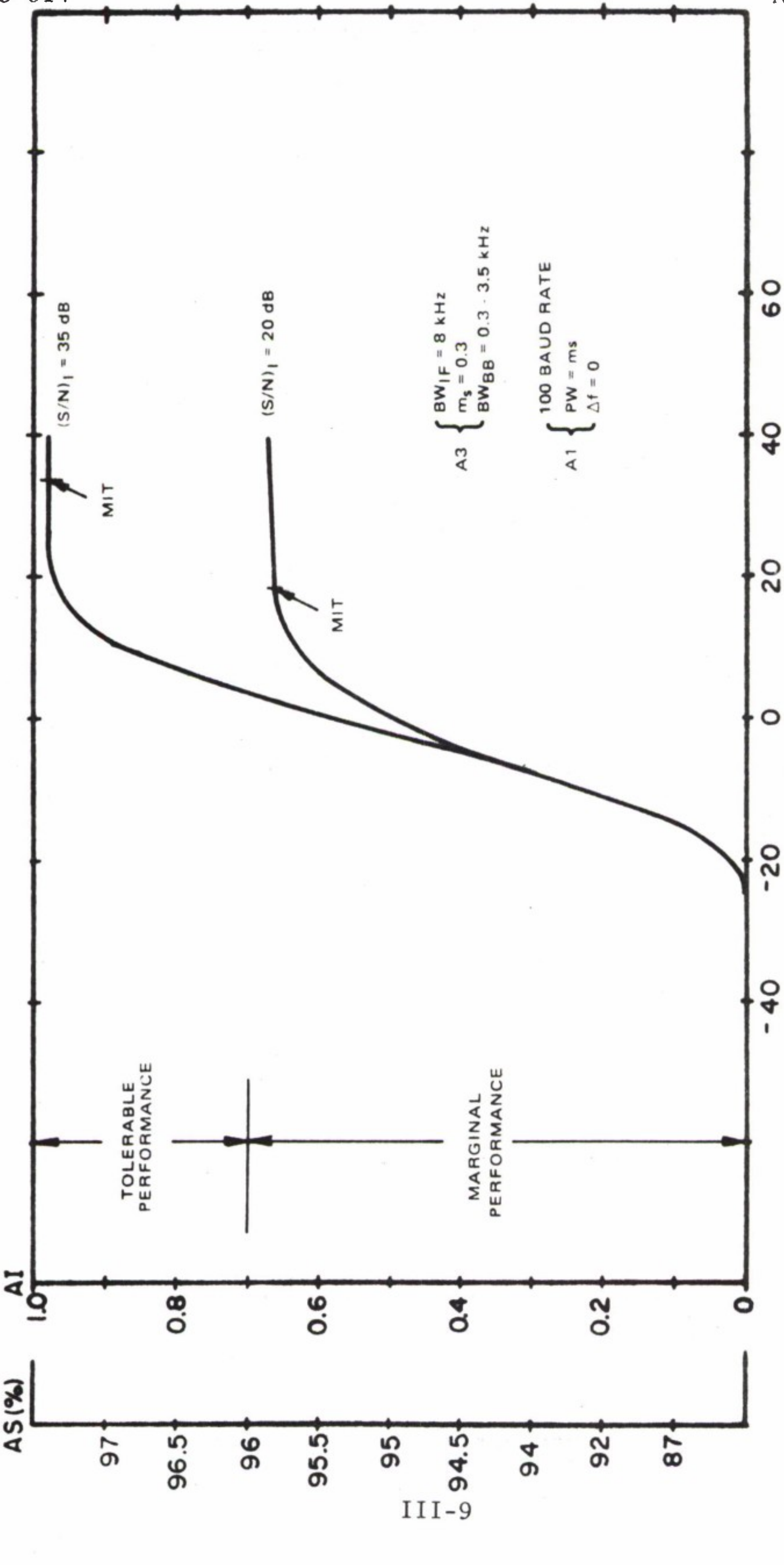


Figure III-7. Performance Degradation Curve For A3 Receiver With A1 Interference (100 Baud Rate, $\Delta f = 0$)

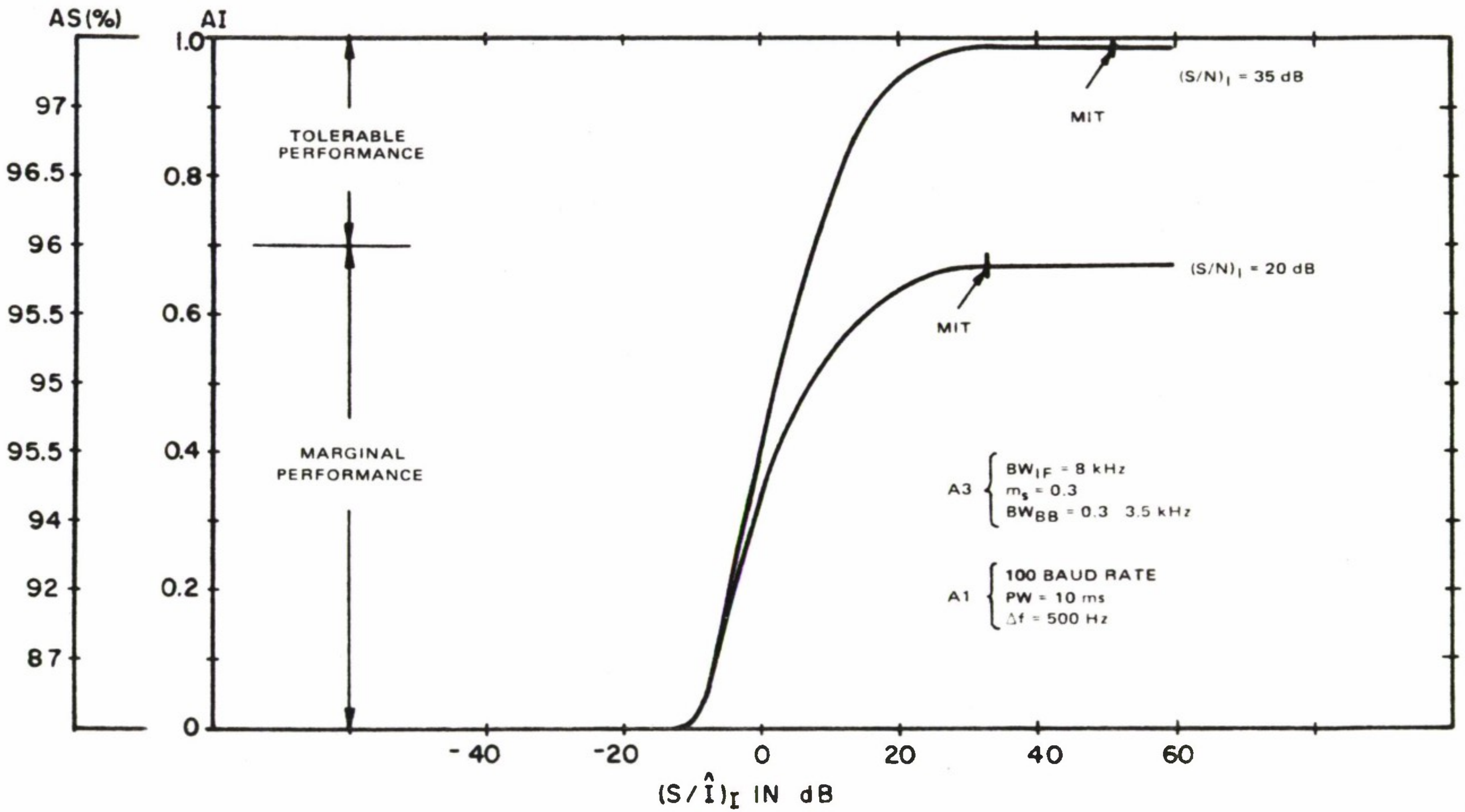


Figure III-8. Performance Degradation Curve For A3 Receiver With A1 Interference (100 Baud Rate, Δf = 500 Hz)

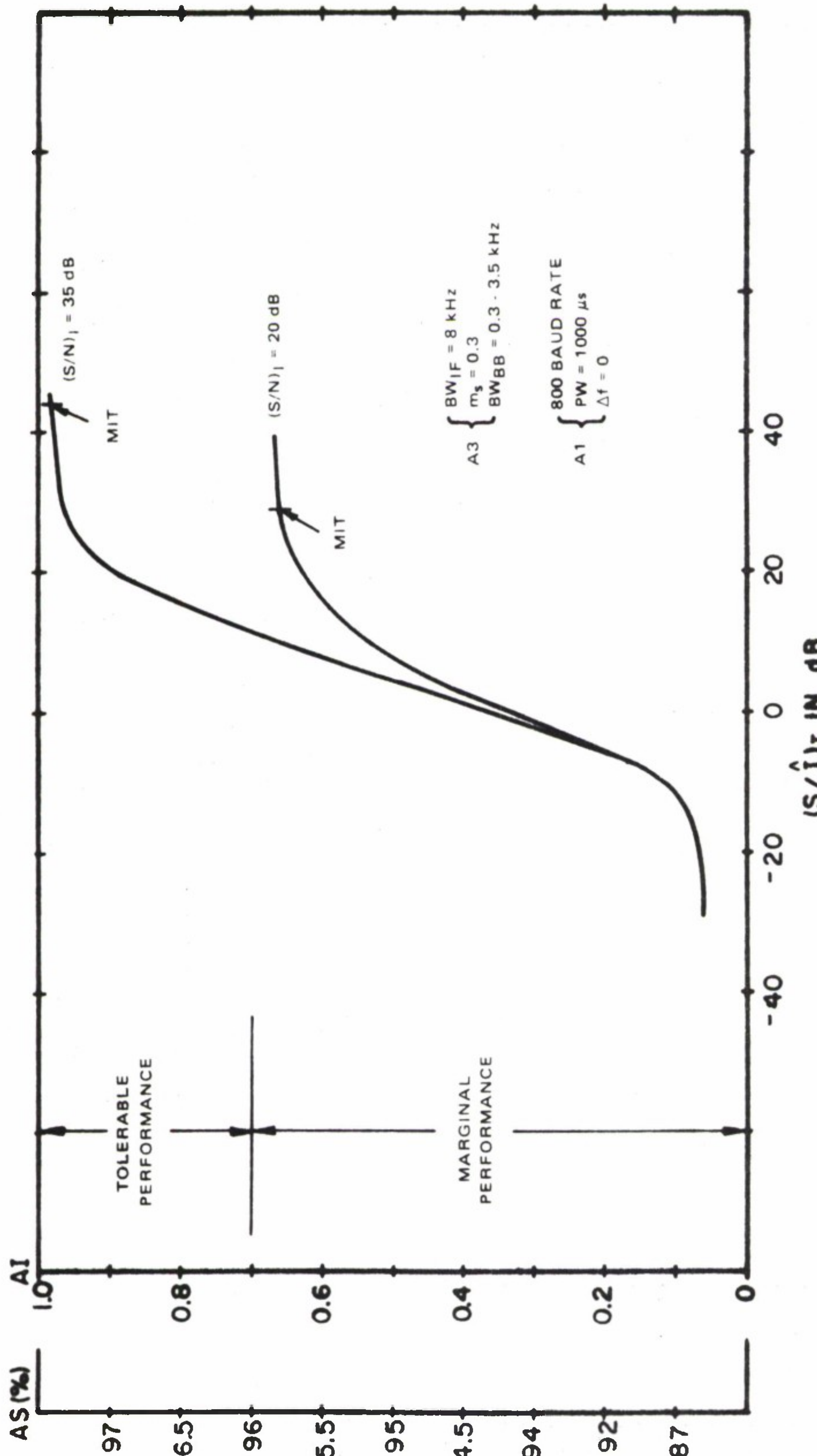


Figure III-9. Performance Degradation Curve For A3 Receiver With A1 Interference (800 Baud Rate, Δf = 0)

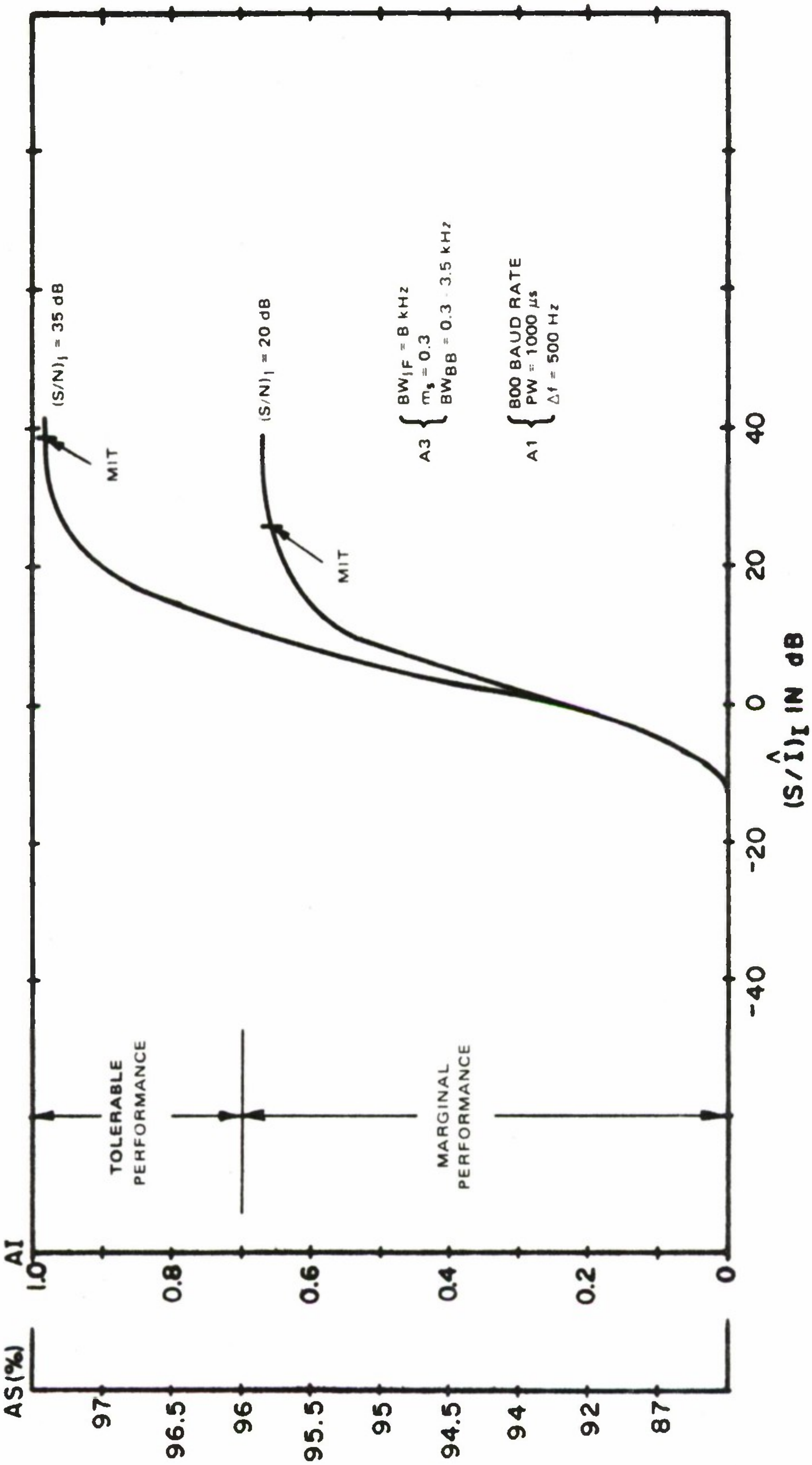


Figure III-10. Performance Degradation Curve For A3 Receiver With A1 Interference (800 Baud Rate, Δf = 500 Hz)

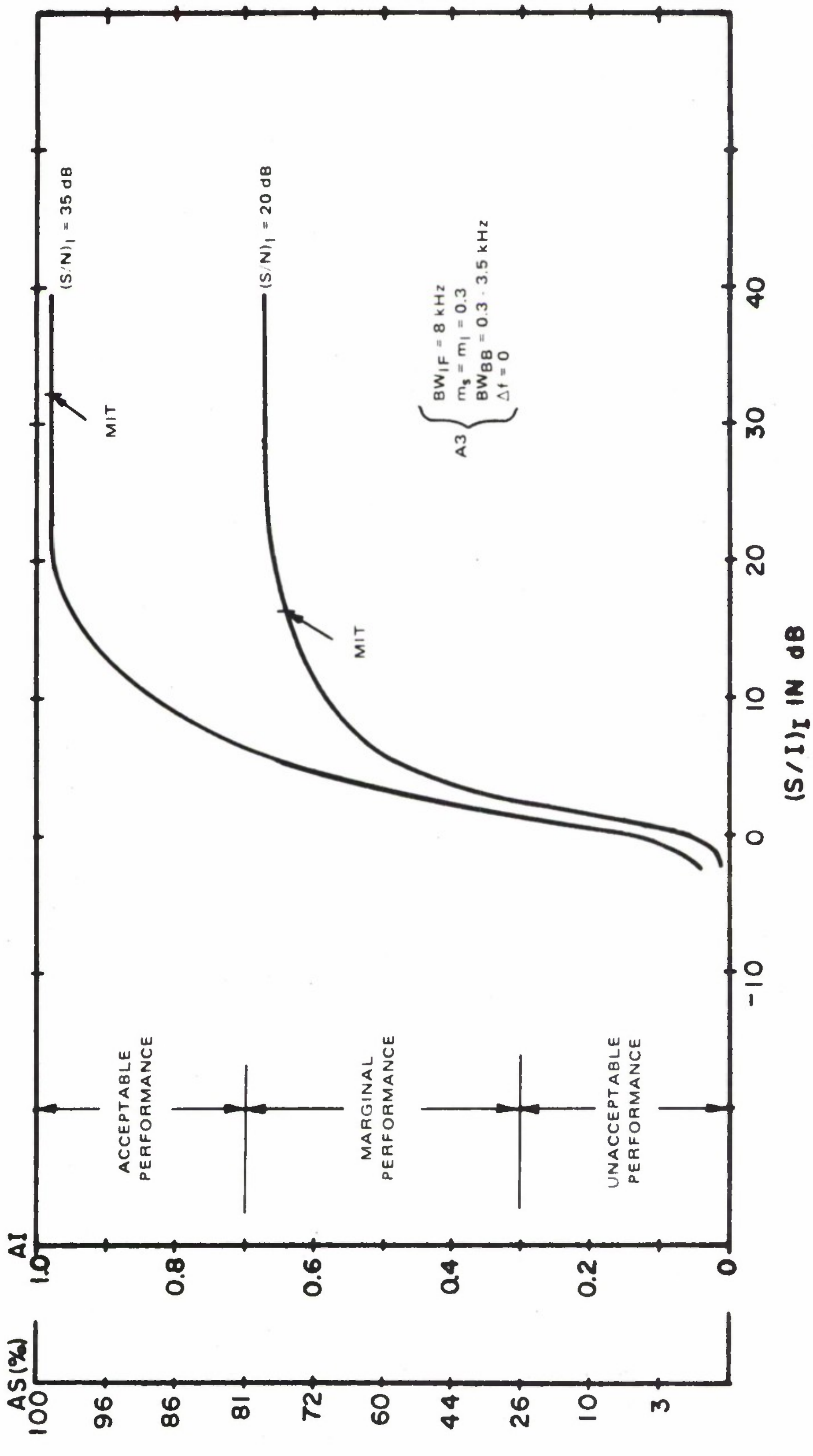


Figure III-11. Performance Degradation Curve For A3 Receiver With A3 Interference ($\Delta f = 0$)

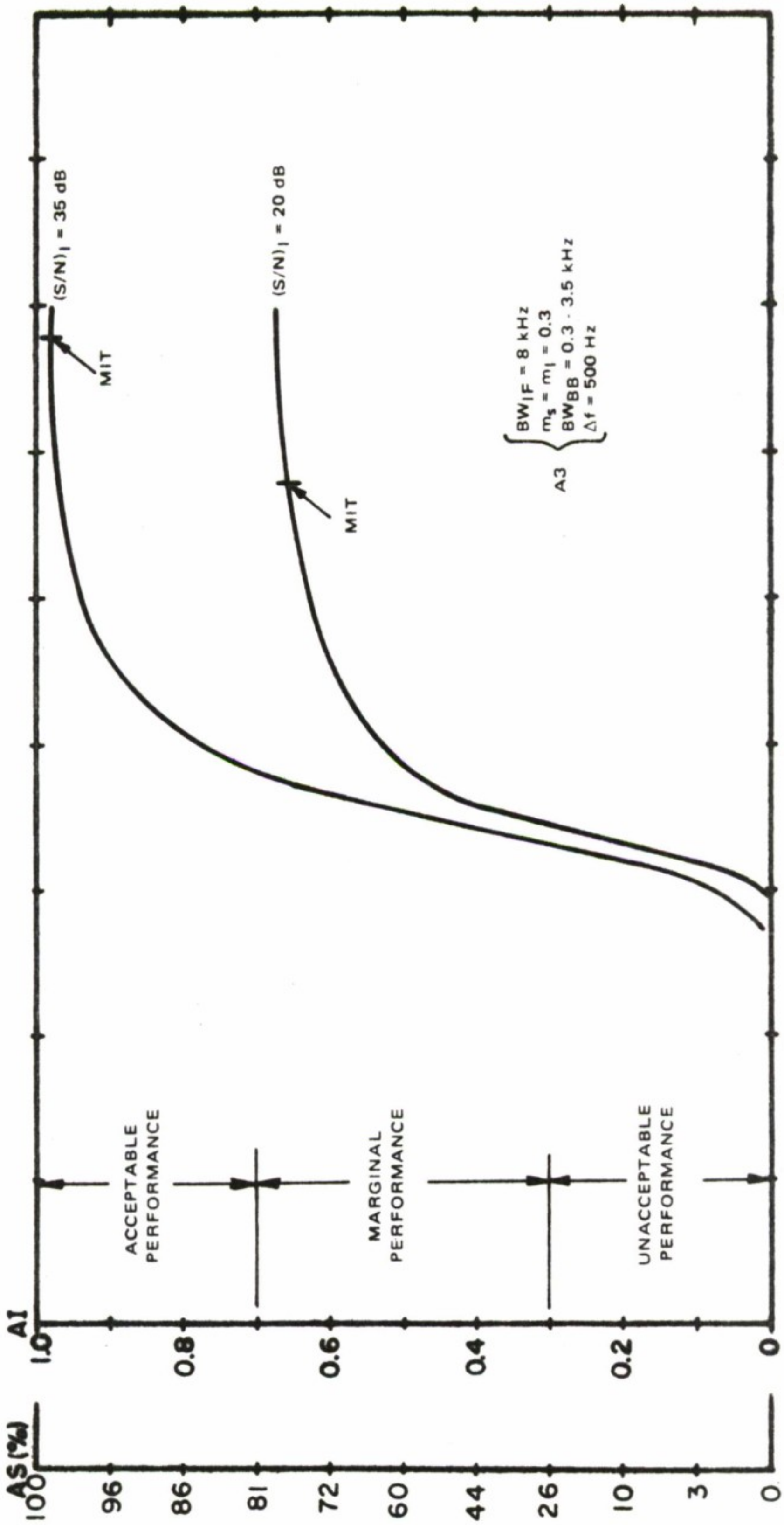


Figure III-12. Performance Degradation Curve For A3 Receiver With A3 Interference (Δf = 500 Hz)

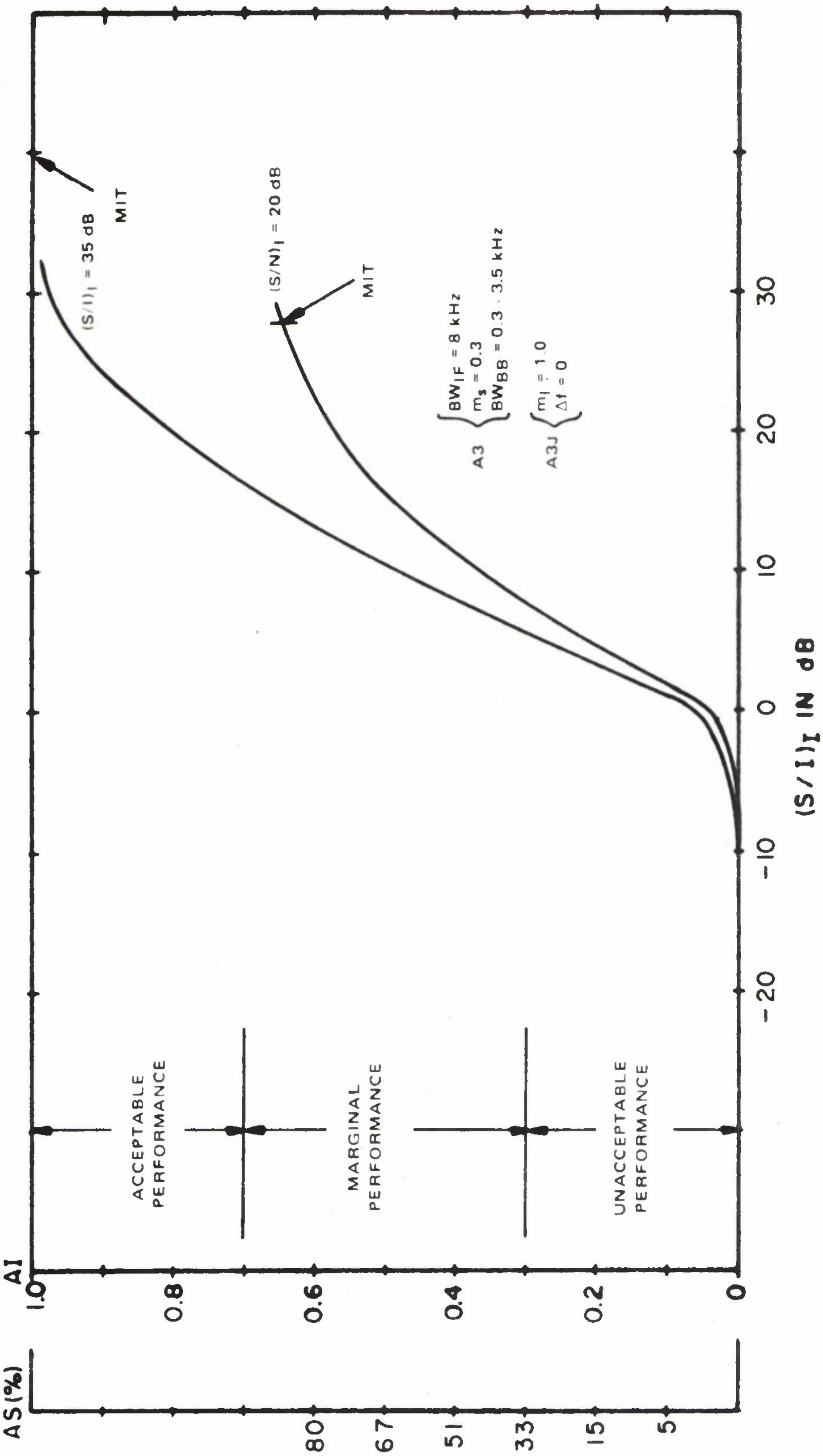


Figure III-13. Performance Degradation Curve For A3 Receiver With A3J Interference (Δf = 0 Hz)

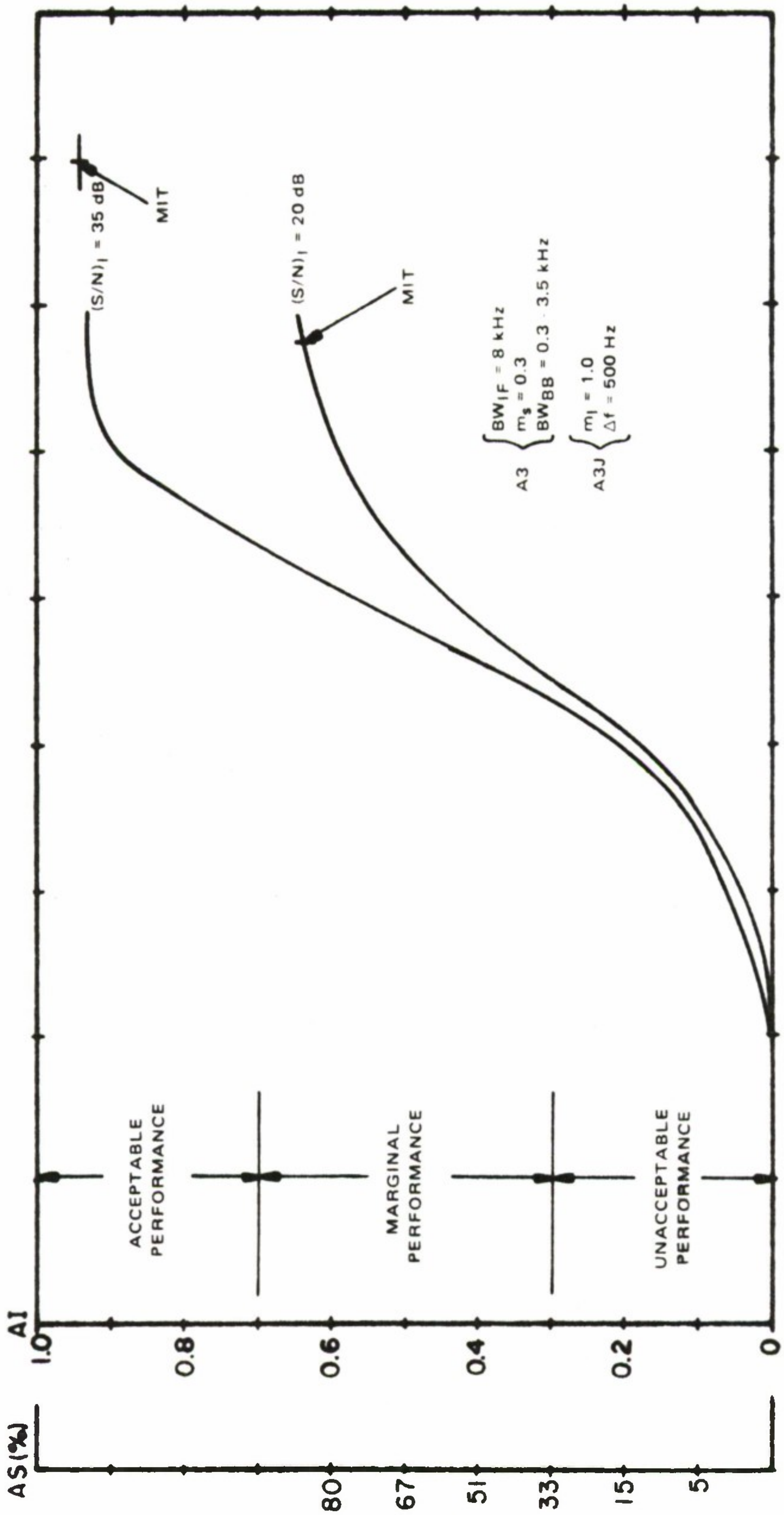


Figure III-14. Performance Degradation Curve For A3 Receiver With A3J Interference (Δf = 500 Hz)

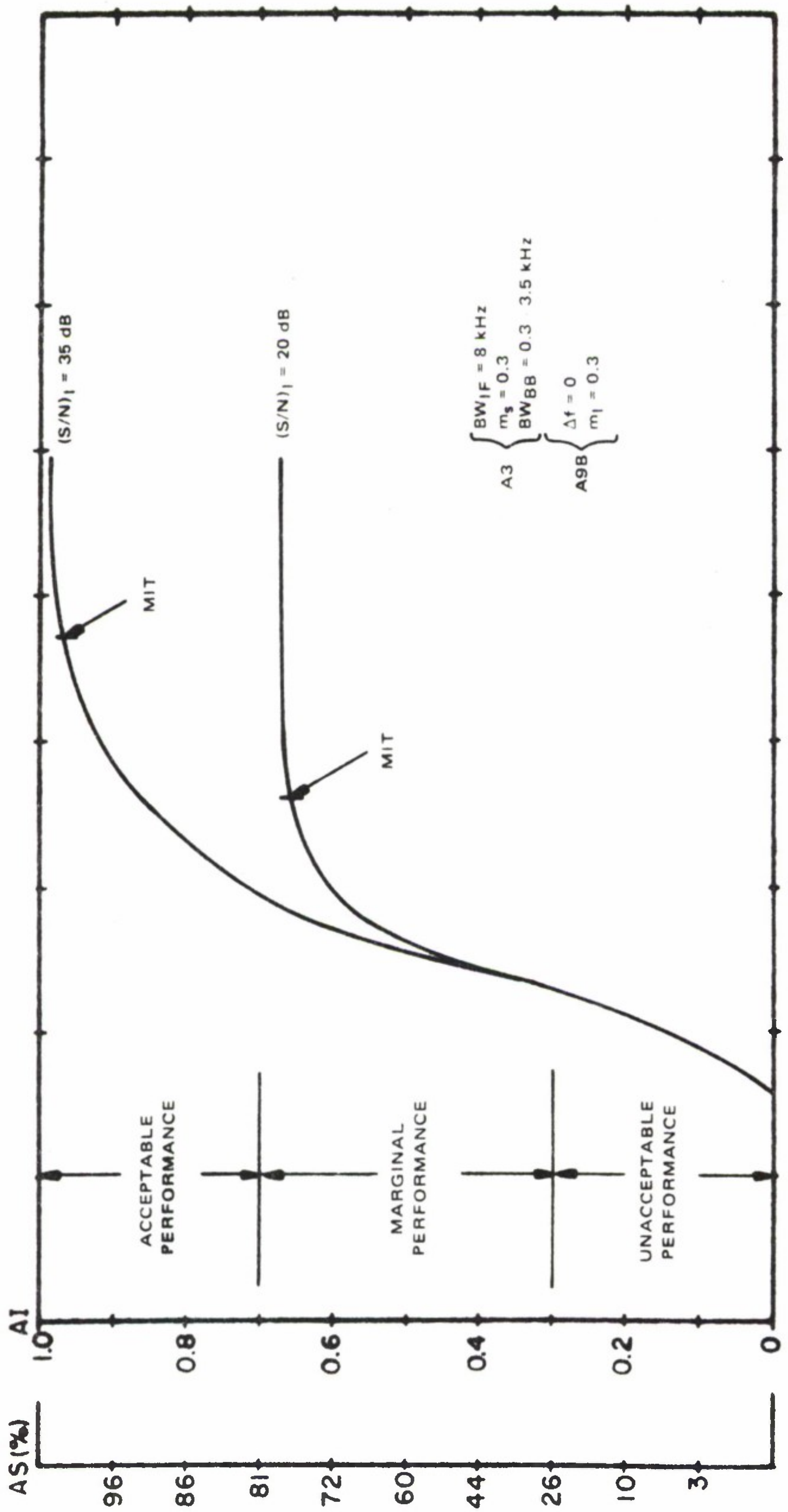


Figure III-15. Performance Degradation Curve For A3 Receiver With A9B Interference (Δf = 0 Hz)

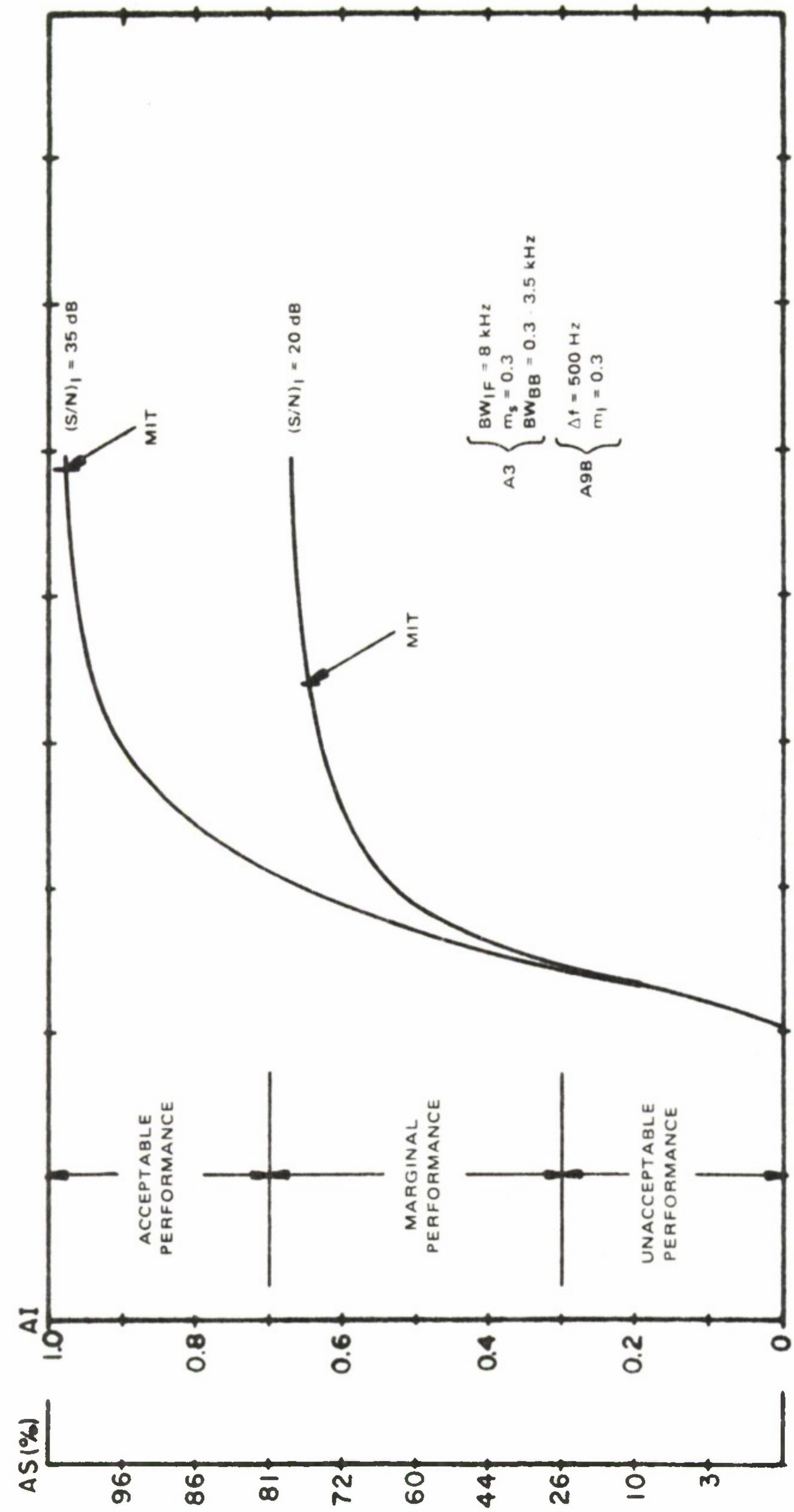


Figure III-16. Performance Degradation Curve For A3 Receiver With A9B Interference (Δf = 500 Hz)

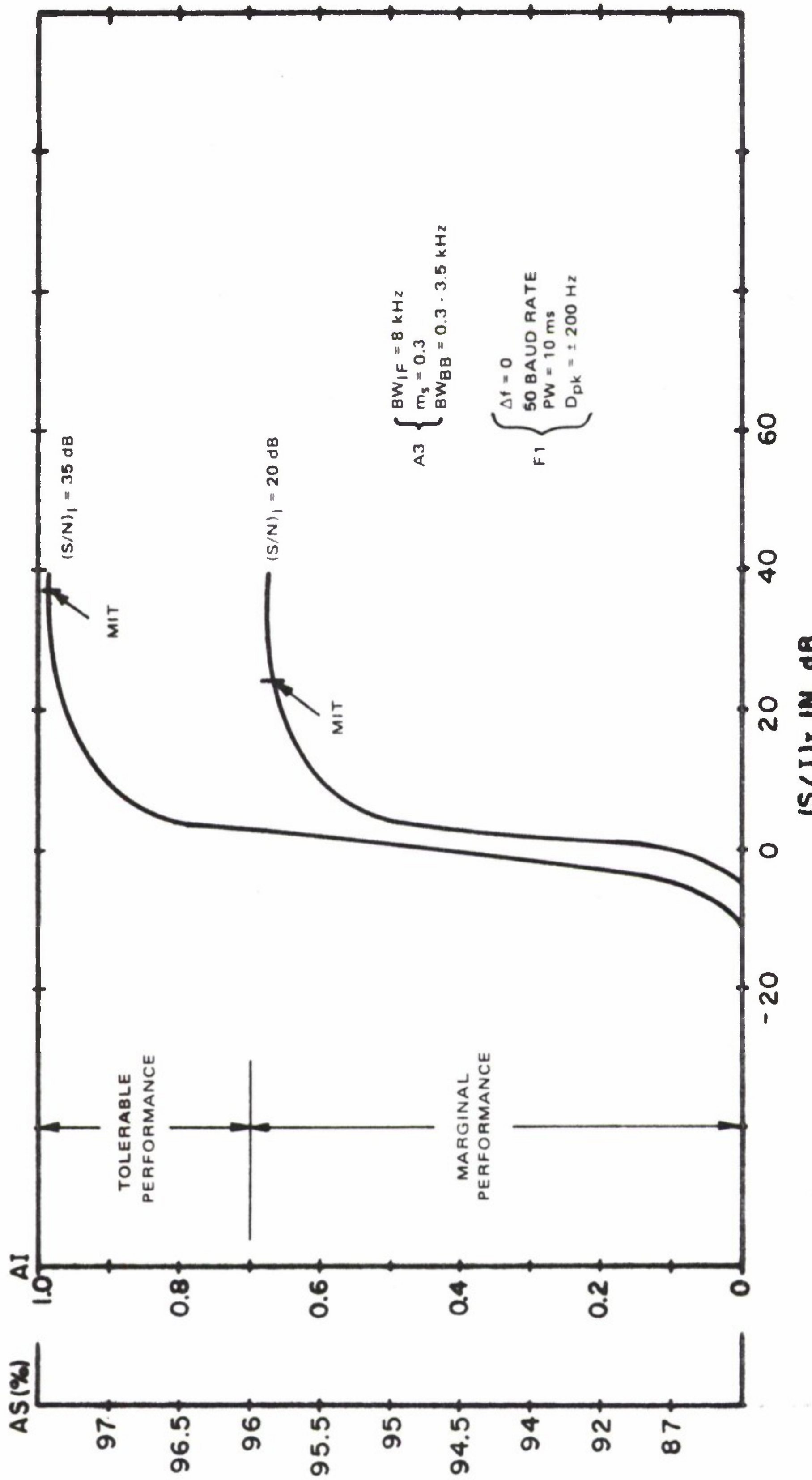


Figure III-17. Performance Degradation Curve For A3 Receiver With F1 Interference (Δf = 0 Hz)

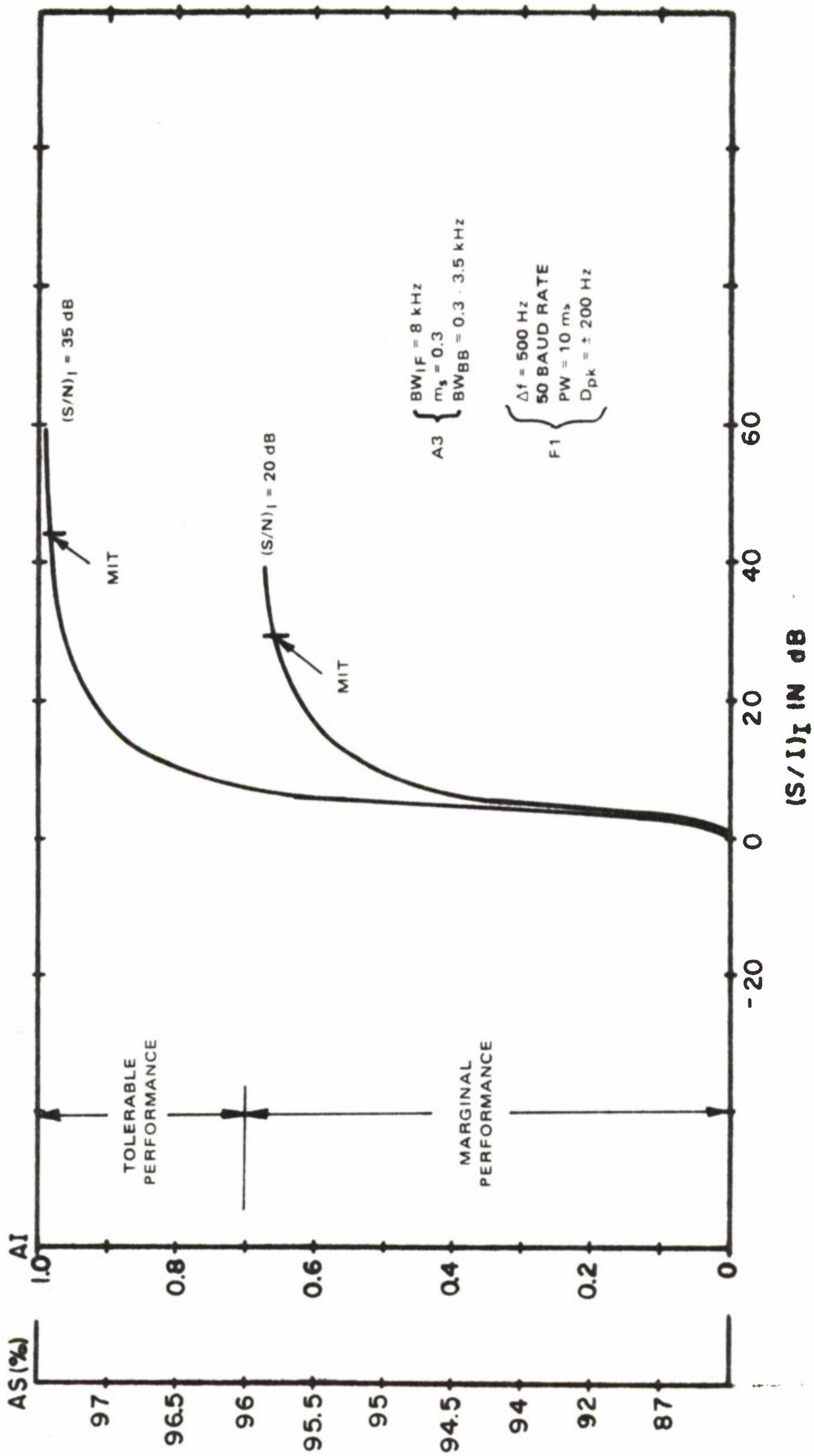


Figure III-18. Performance Degradation Curve For A3 Receiver With F1 Interference (Δf = 500 Hz)

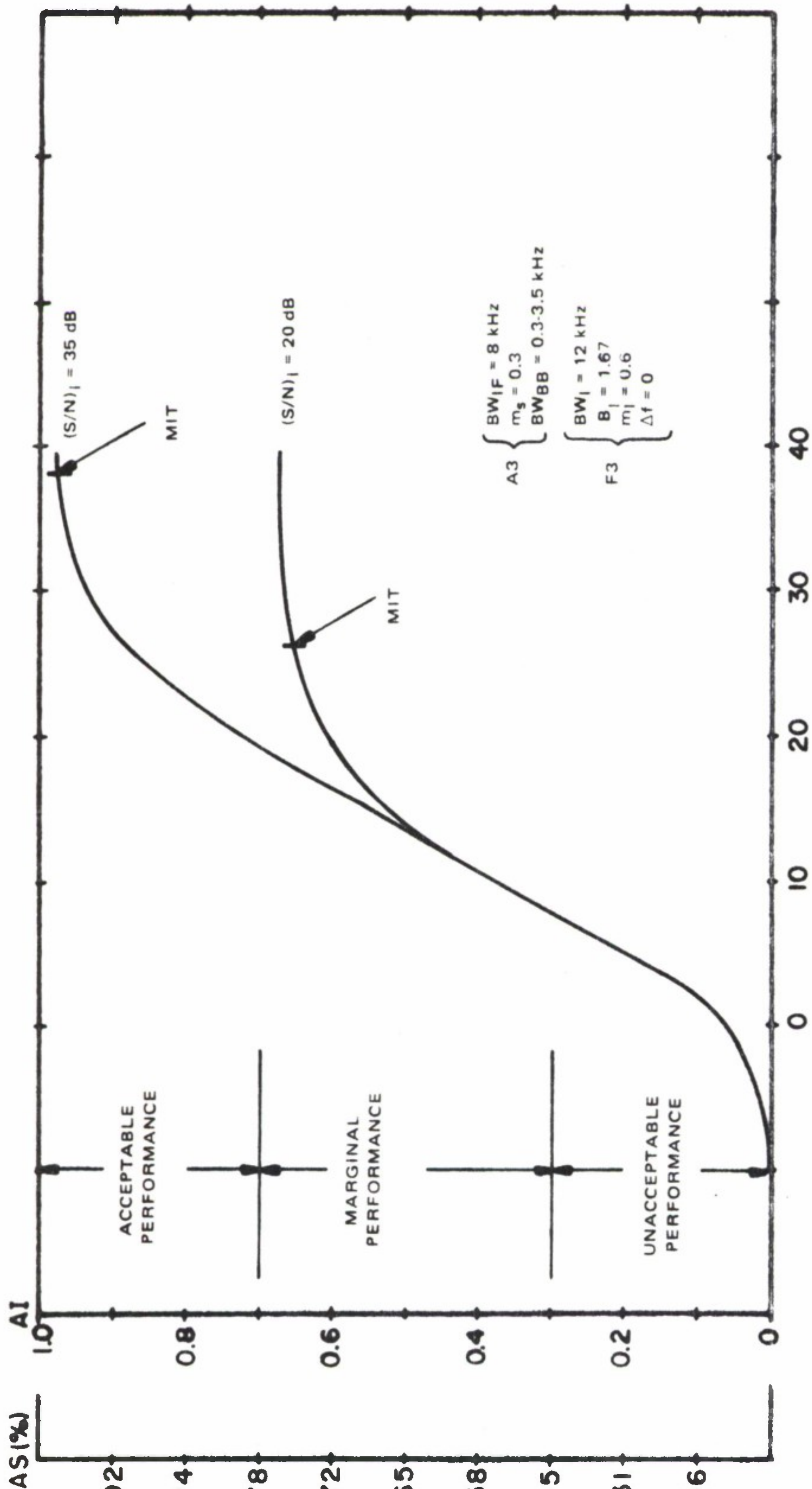


Figure III-19. Performance Degradation Curve For A3 Receiver With F3 Interference

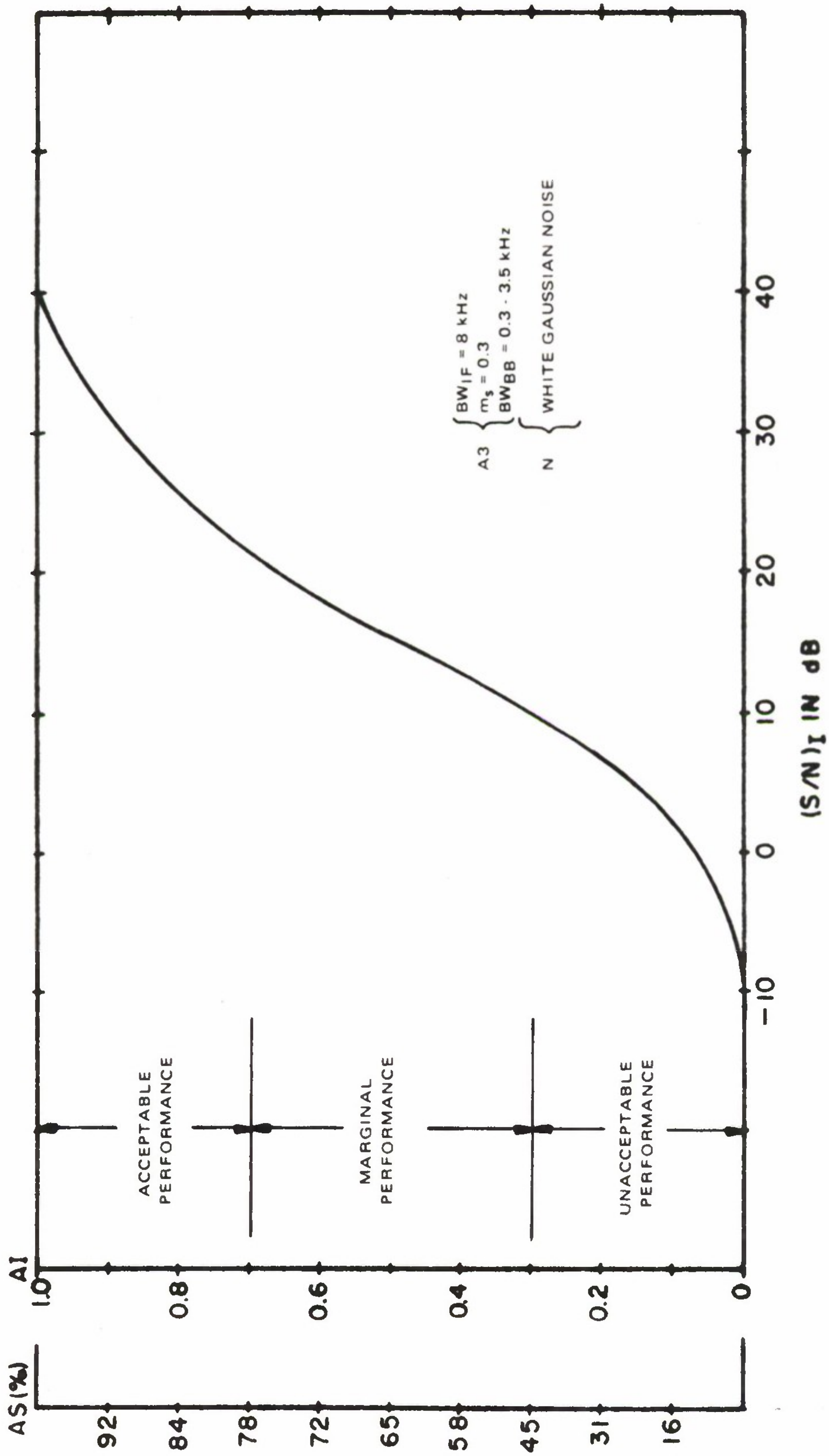


Figure III-20. Performance Degradation Curve For A3 Receiver With Noise

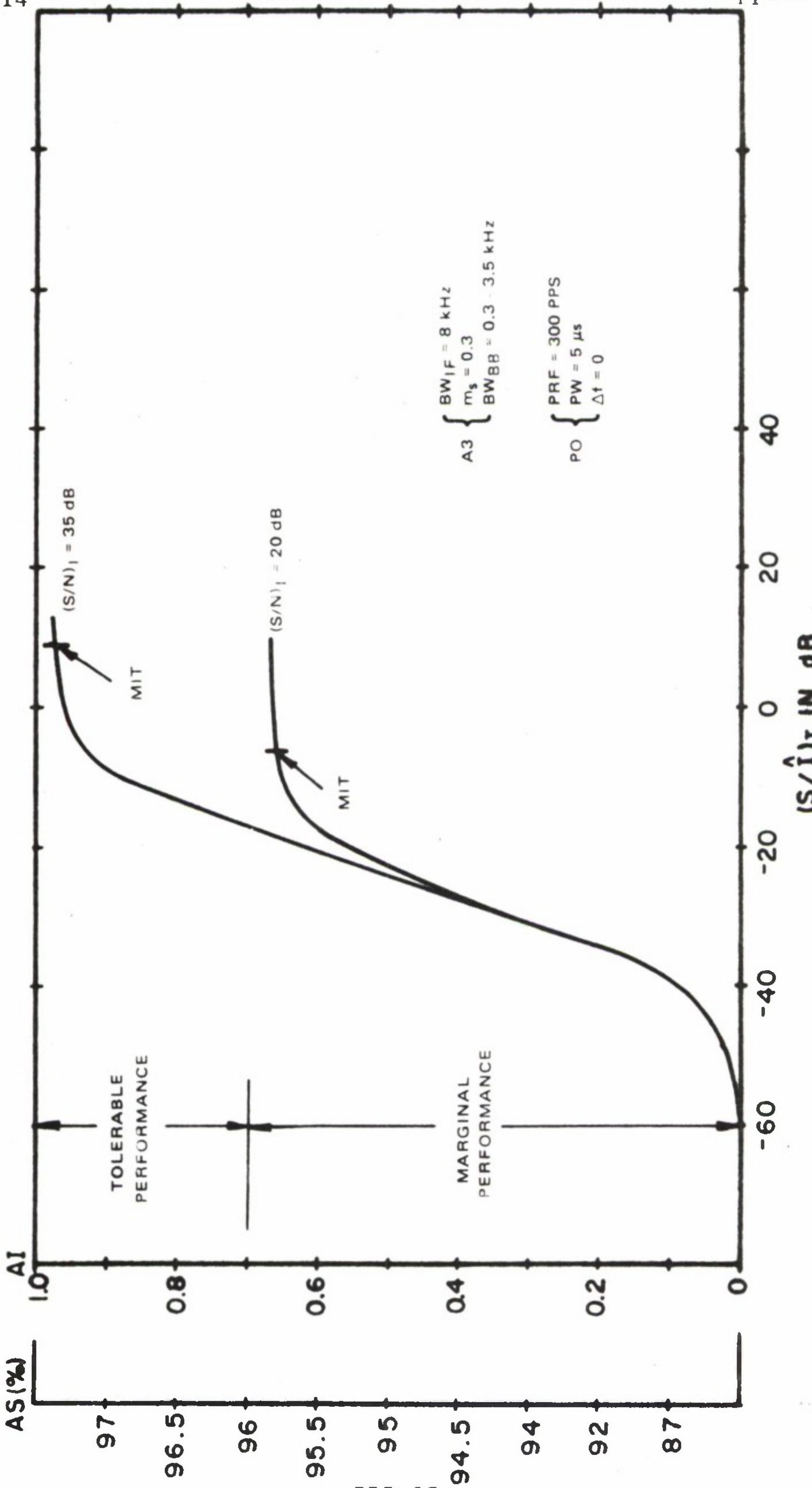


Figure III-21. Performance Degradation Curve For A3 Receiver With PO Interference (Δf = 0 Hz)

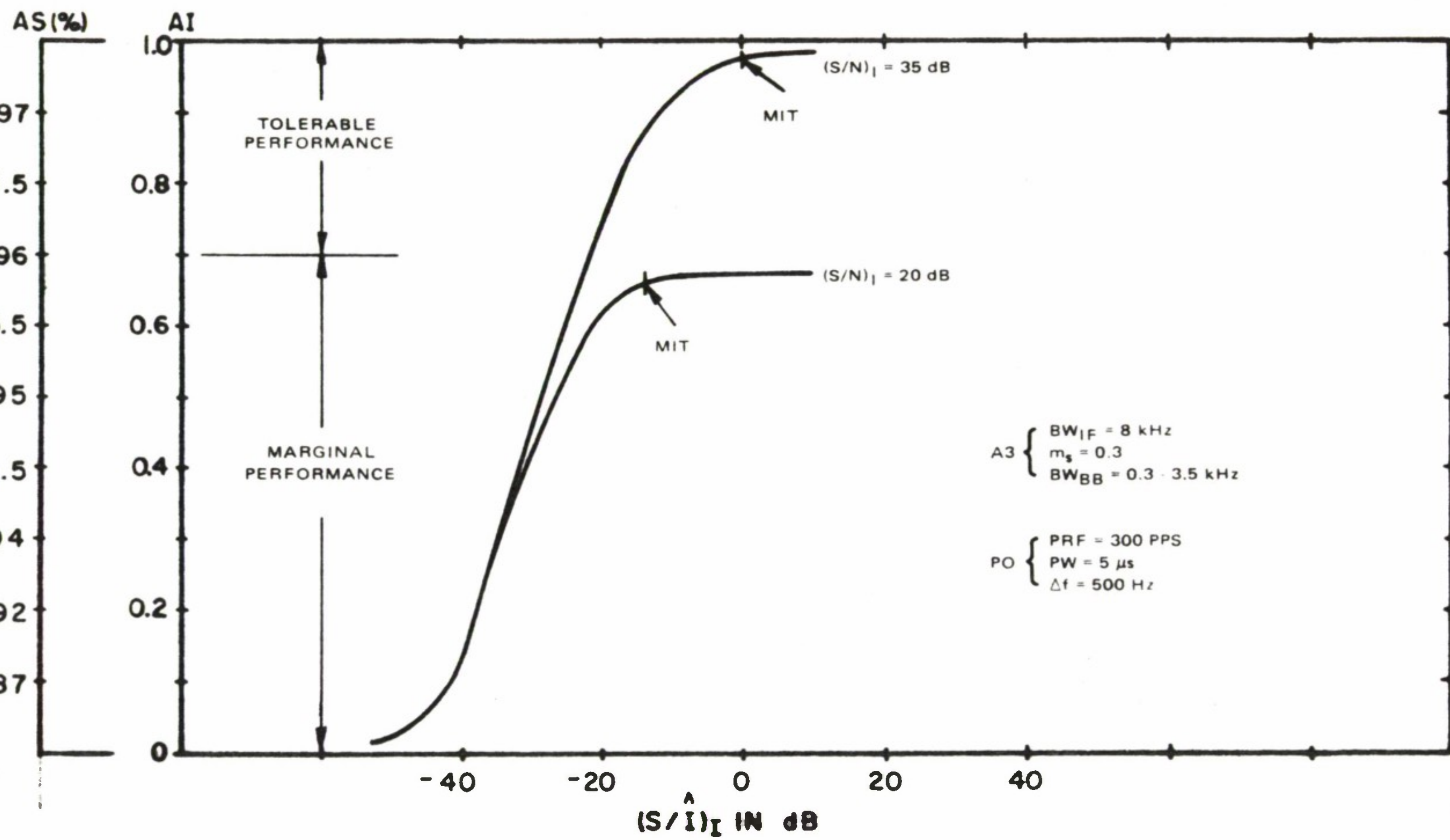


Figure III-22. Performance Degradation Curve For A3 Receiver With PO Interference (Δf = 500 Hz)

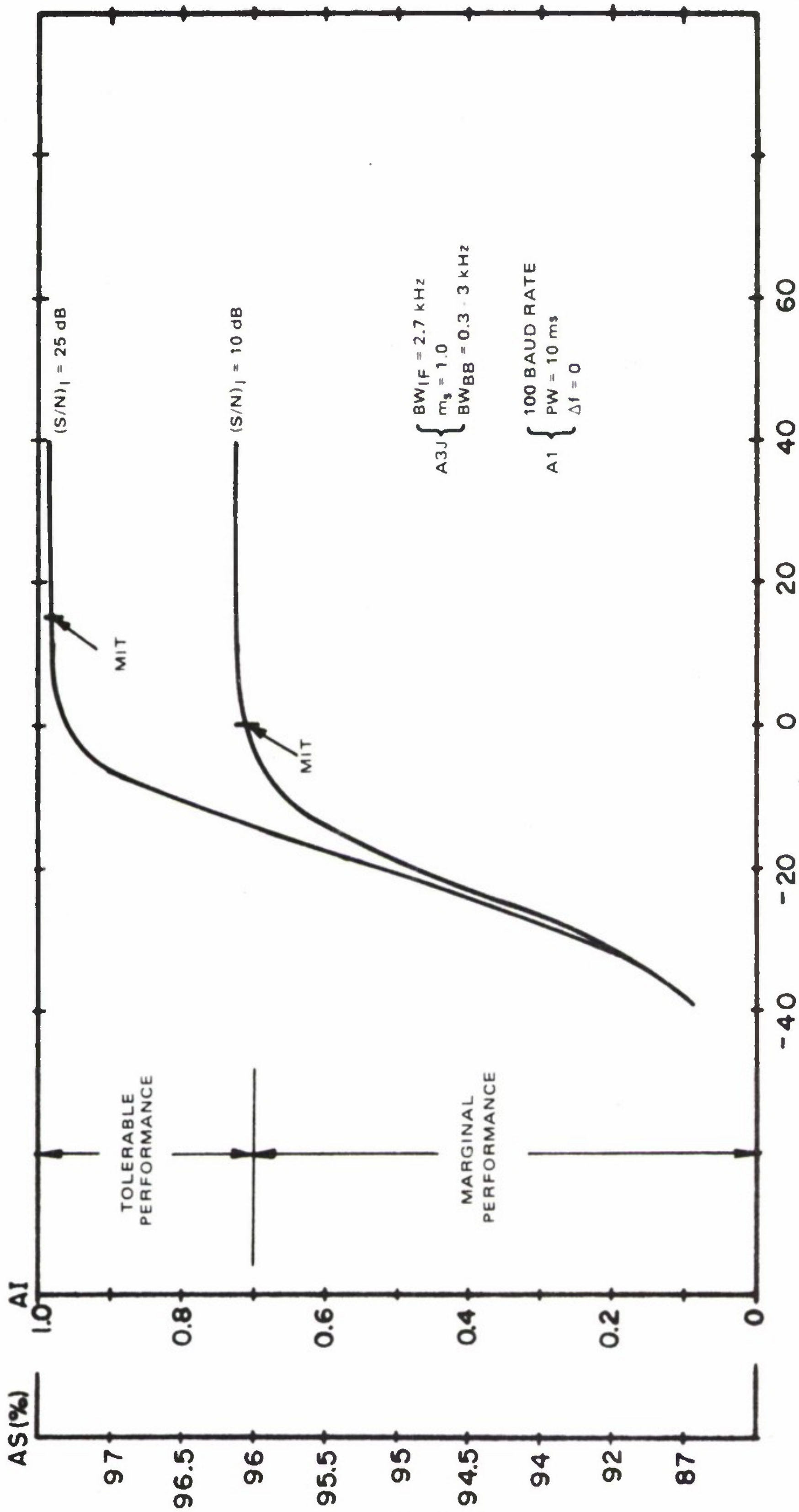


Figure III-23. Performance Degradation Curve For A3J Receiver With A1 Interference (100 Baud Rate, Δf = 0 Hz)

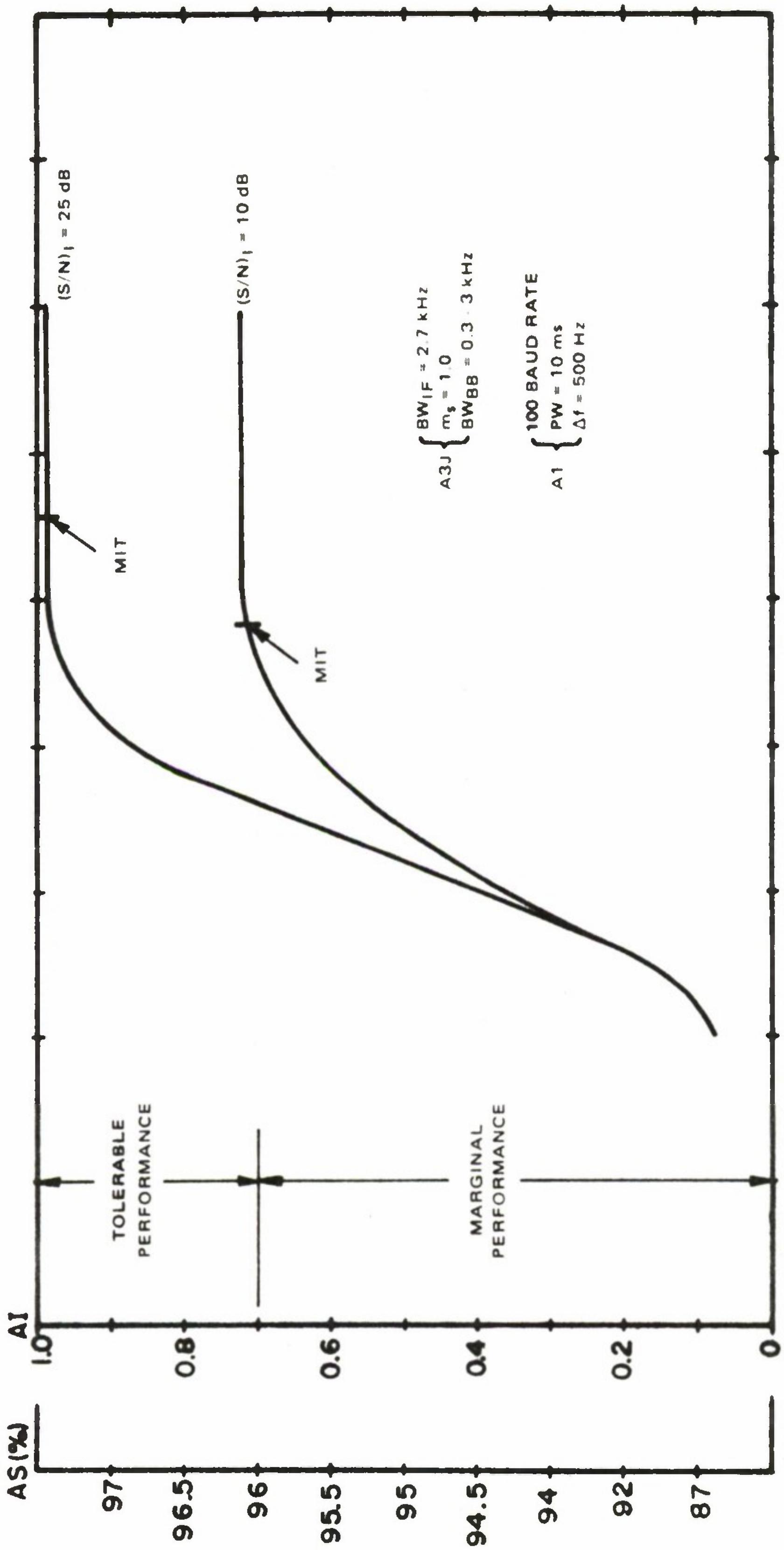


Figure III-24. Performance Degradation Curve For A3J Receiver With A1 Interference (100 Baud Rate, $\Delta f = 500$ Hz)

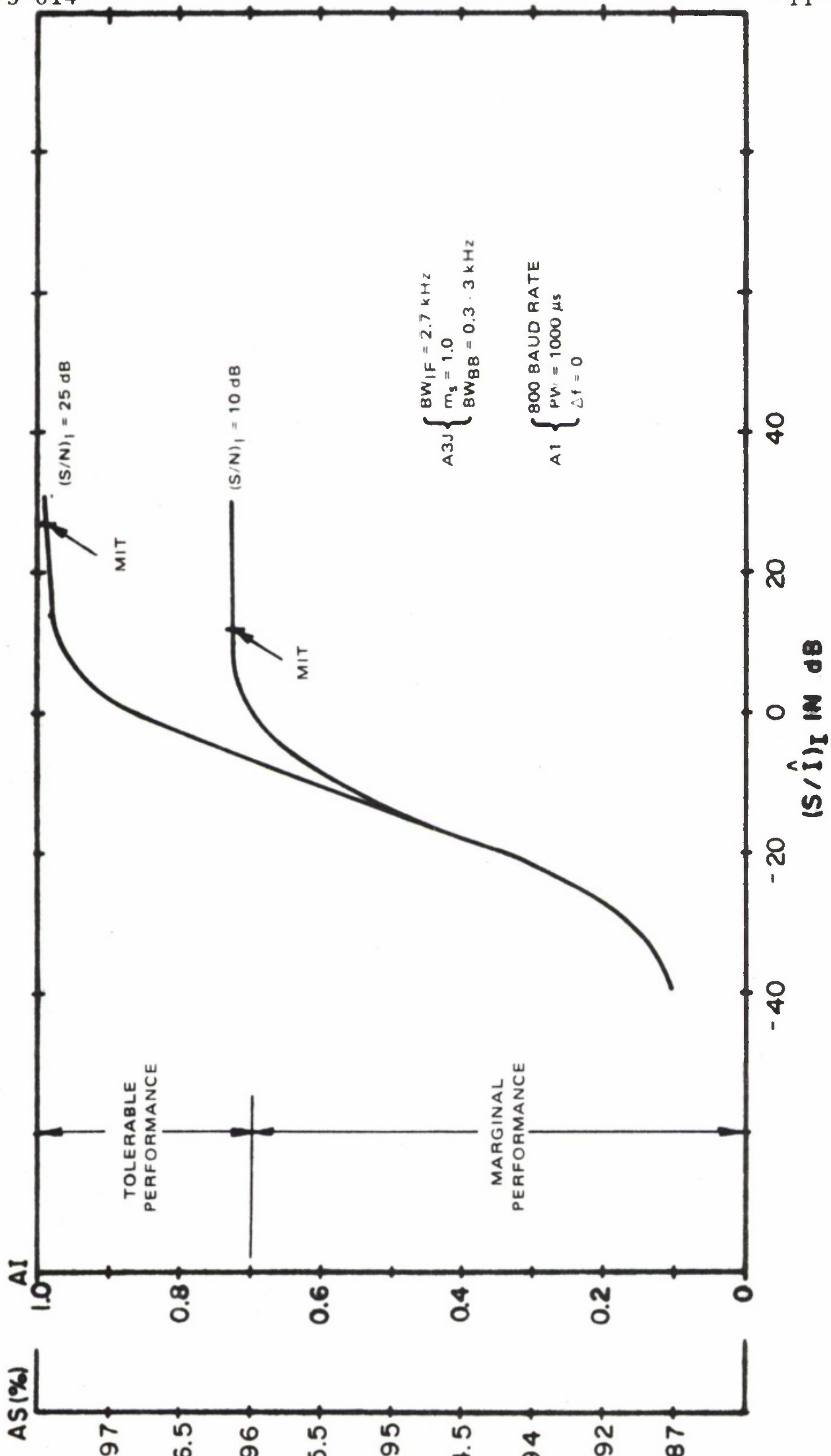


Figure III-25. Performance Degradation Curve For A3J Receiver With A1 Interference (800 Baud Rate, $\Delta f = 0$ Hz)

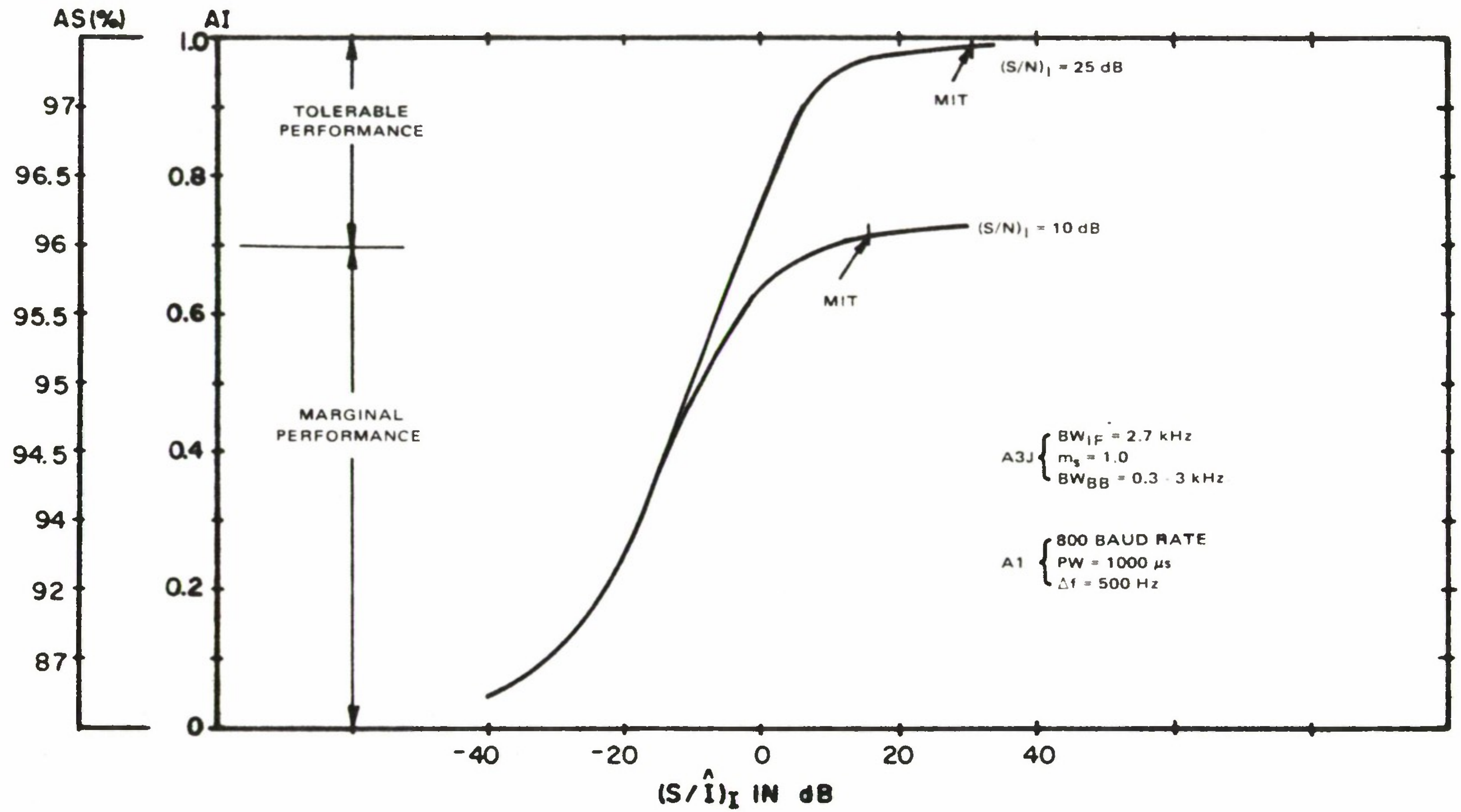


Figure III-26. Performance Degradation Curve For A3J Receiver With A1 Interference (800 Baud Rate, $\Delta f = 500$ Hz)

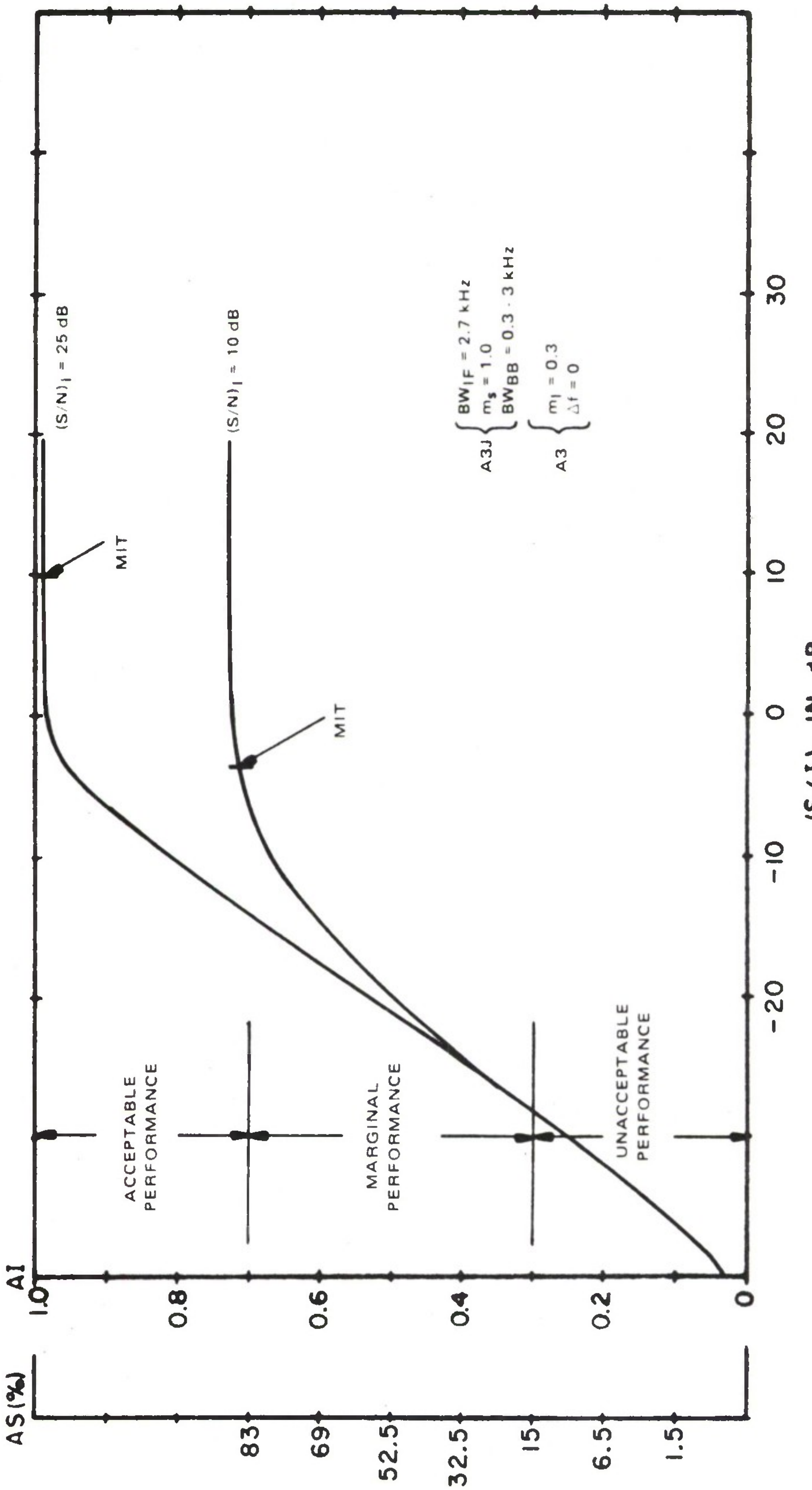


Figure III-27. Performance Degradation Curve For A3J Receiver With A3 Interference (Δf = 0 Hz)

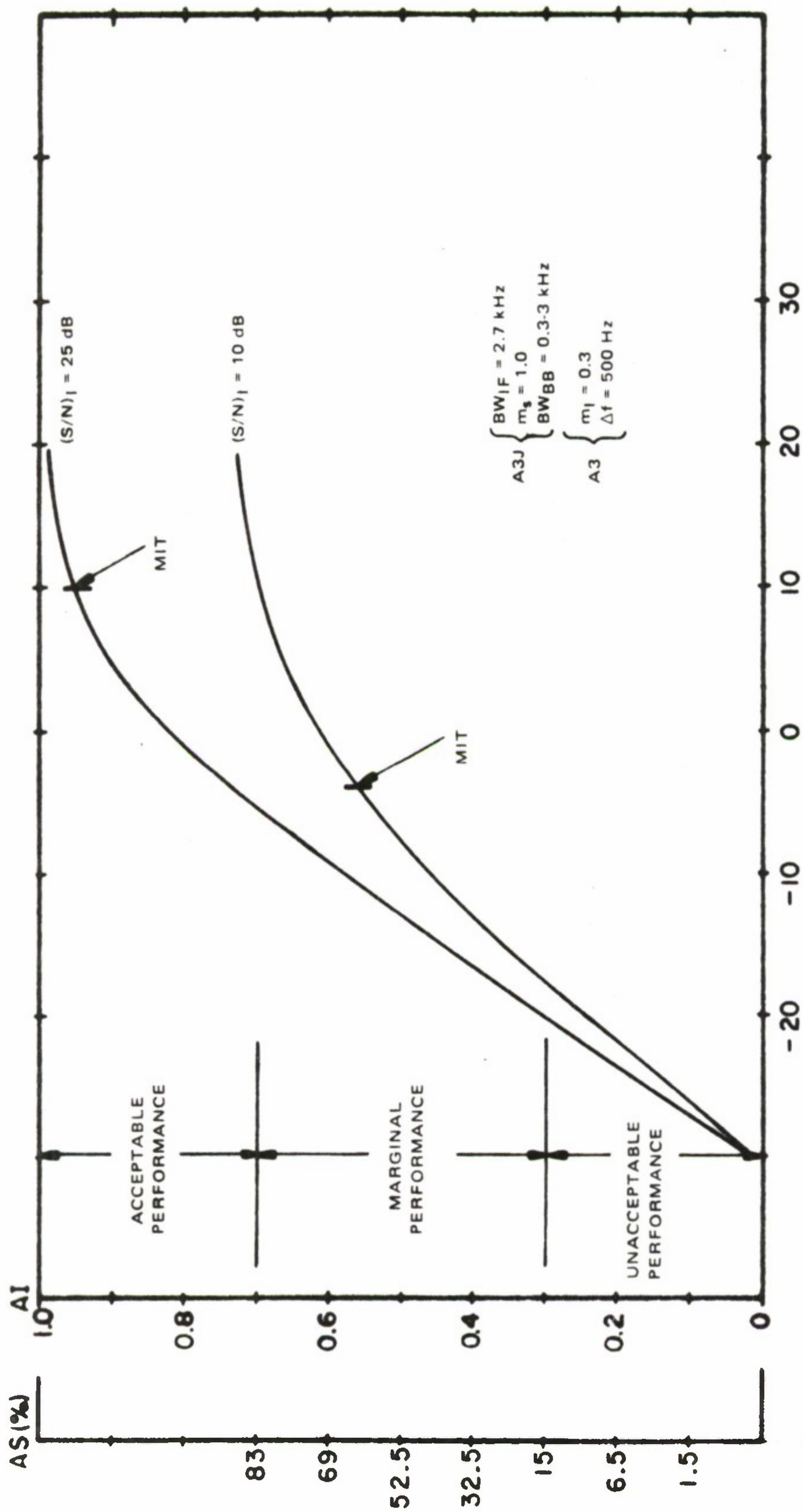


Figure III-28. Performance Degradation Curve For A3J Receiver With A3 Interference (Δf = 500 Hz)

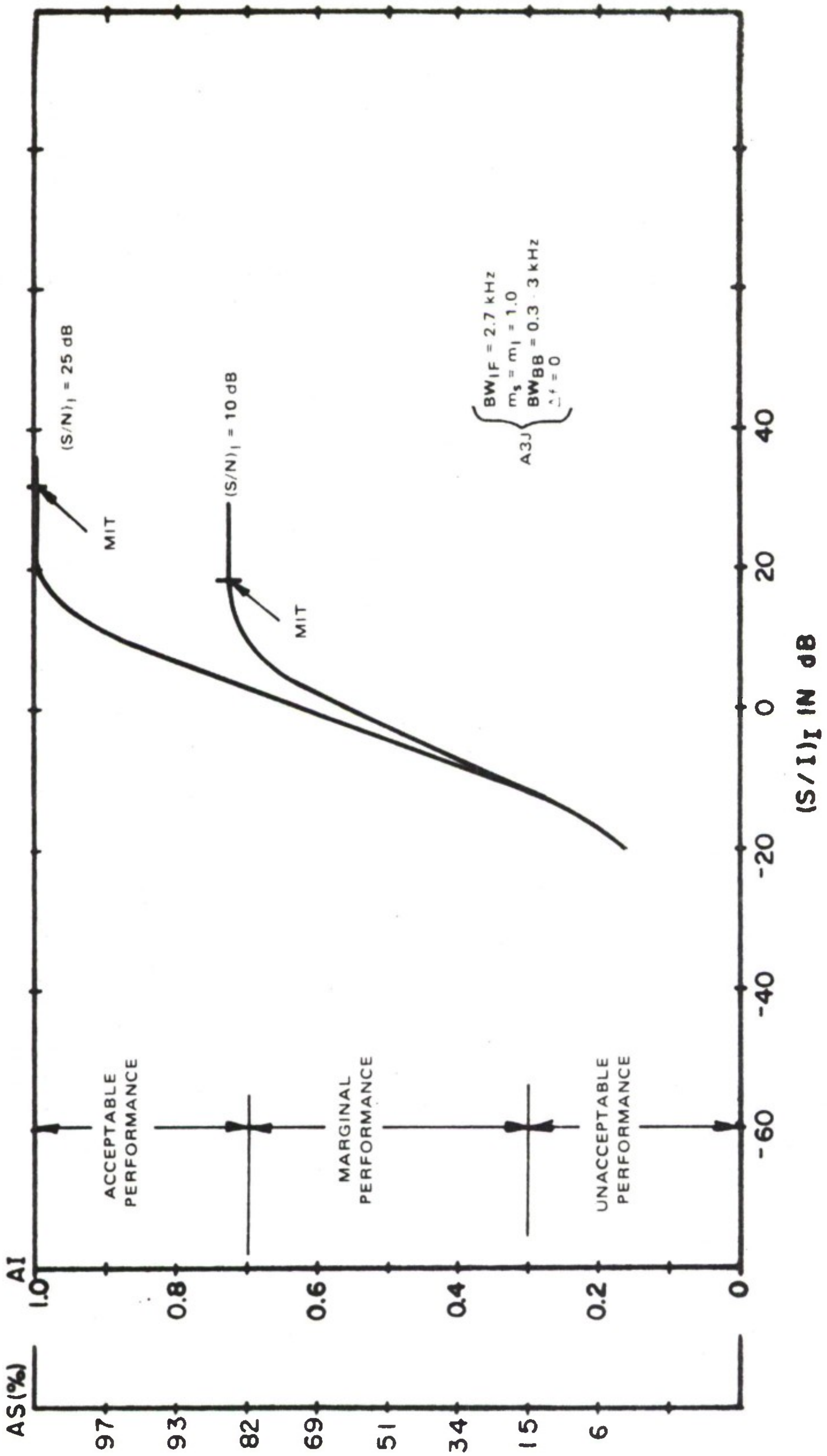


Figure III-29. Performance Degradation Curve For A3J Receiver With A3J Interference (Δf = 0 Hz)

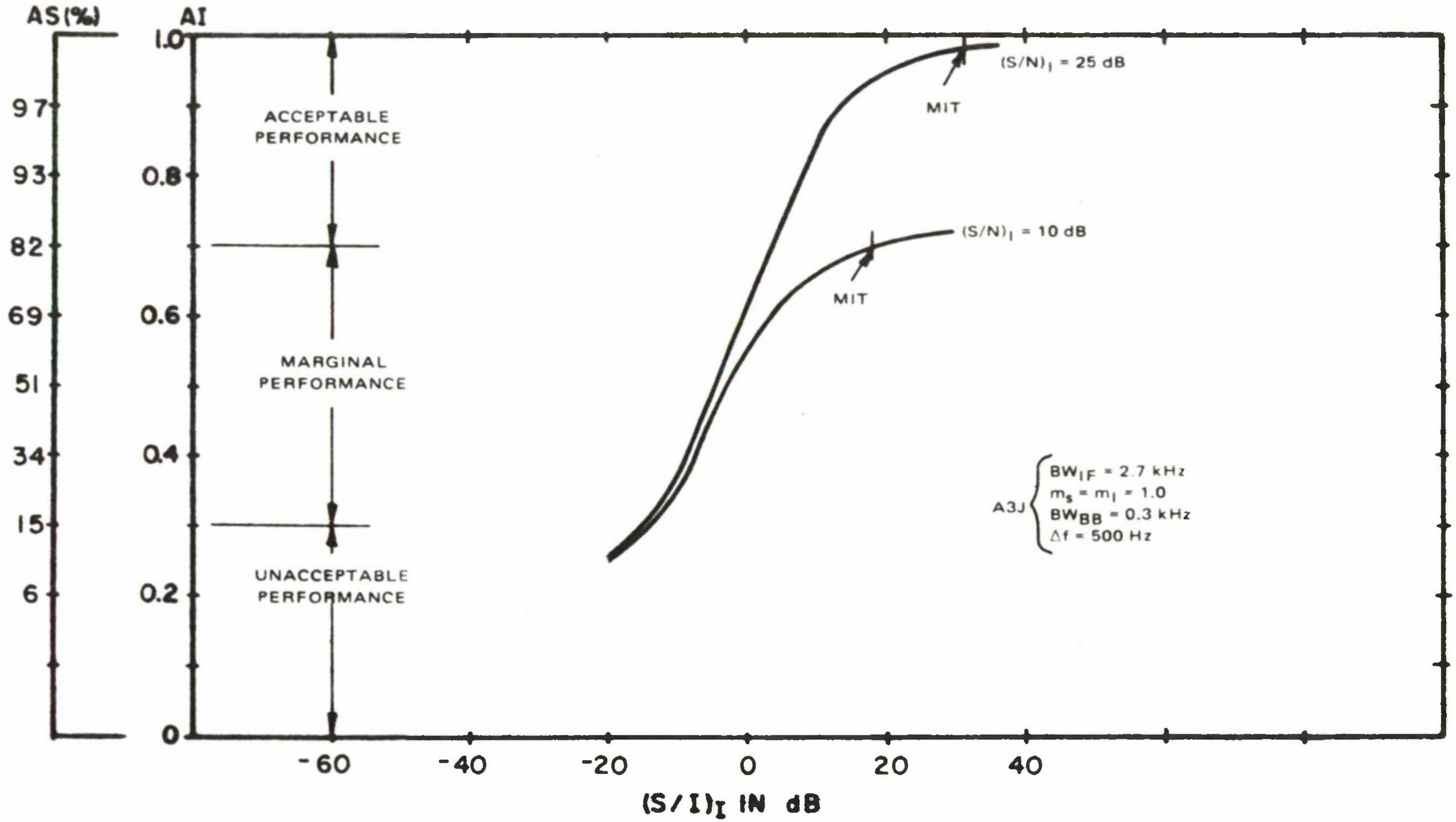


Figure III-30. Performance Degradation Curve For A3J Receiver With A3J Interference (Δf = 500 Hz)

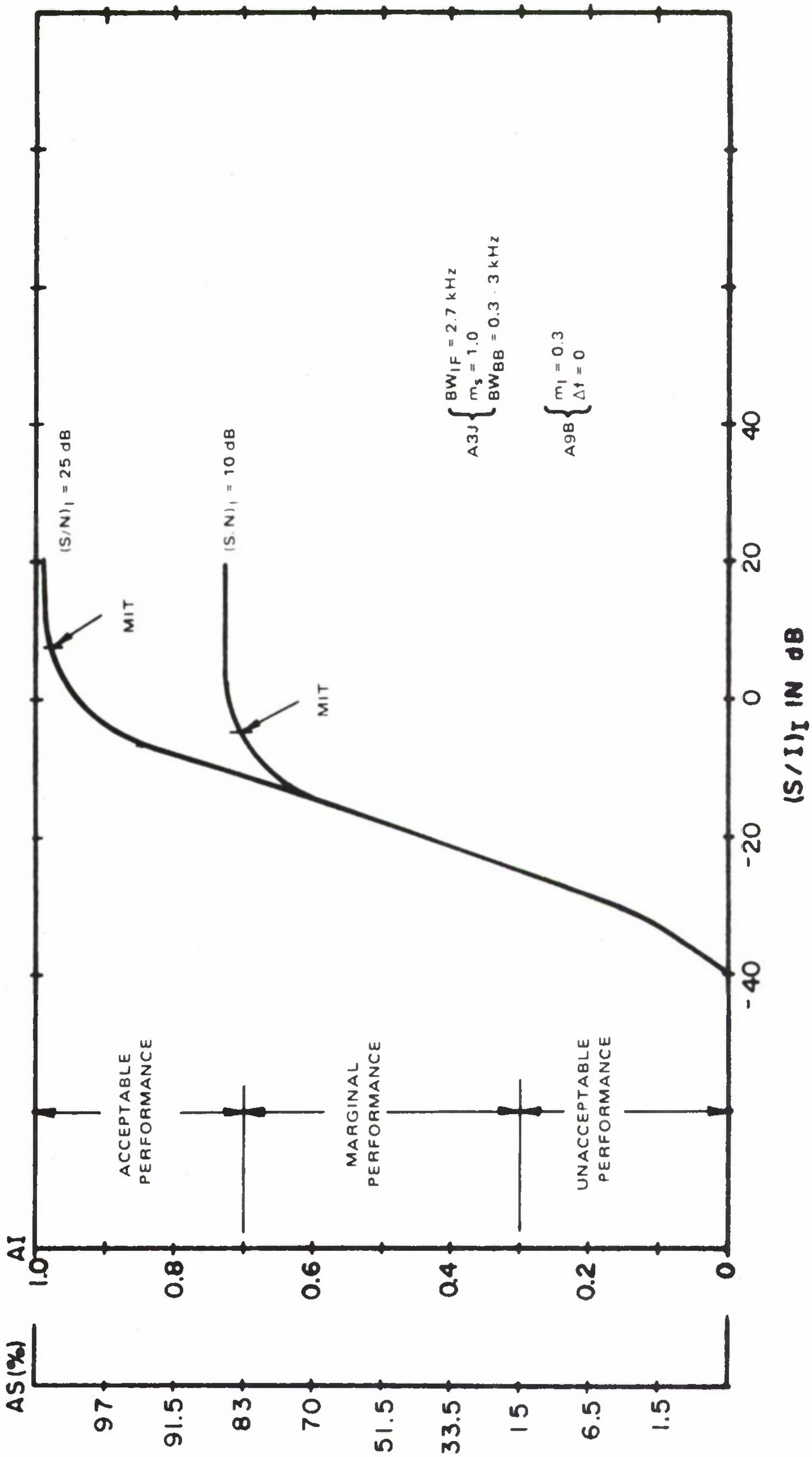


Figure III-31. Performance Degradation Curve For A3J Receiver With A9B Interference (Δf = 0 Hz)

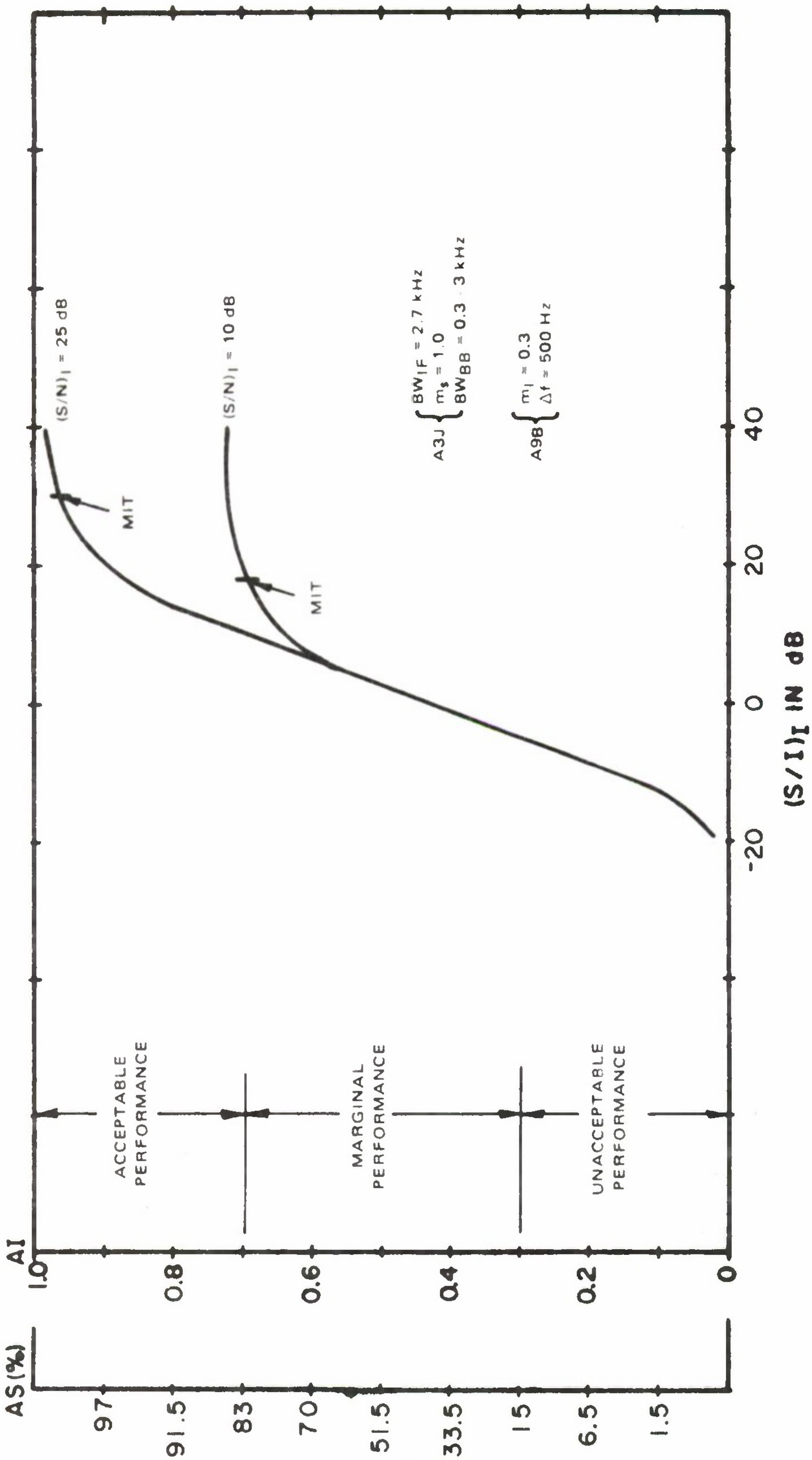


Figure III-32. Performance Degradation Curve A3J Receiver With A9B Interference (Δf = 500 Hz)

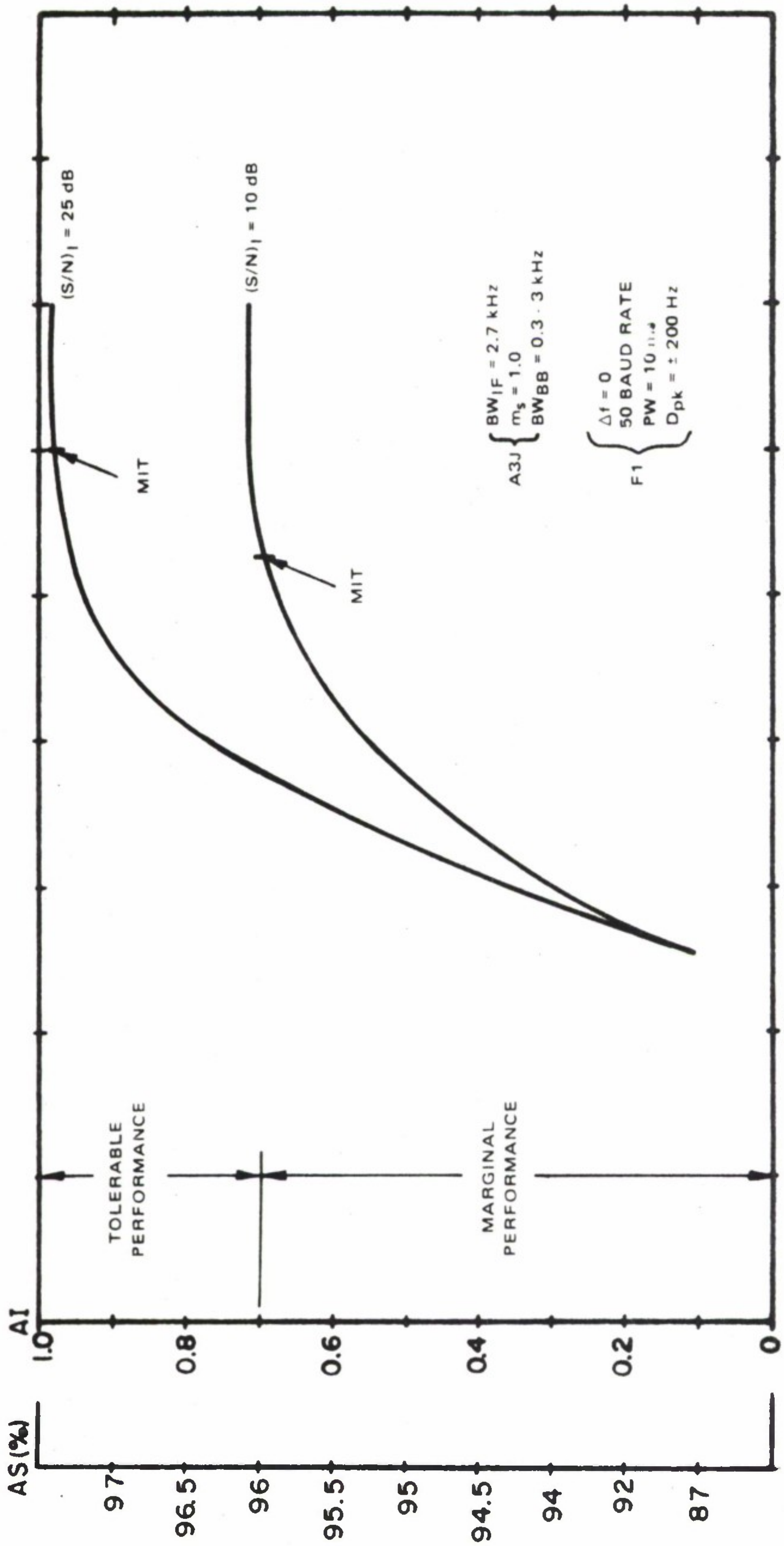


Figure III-33. Performance Degradation Curve For A3J Receiver With F1 Interference (Δf = 0 Hz)

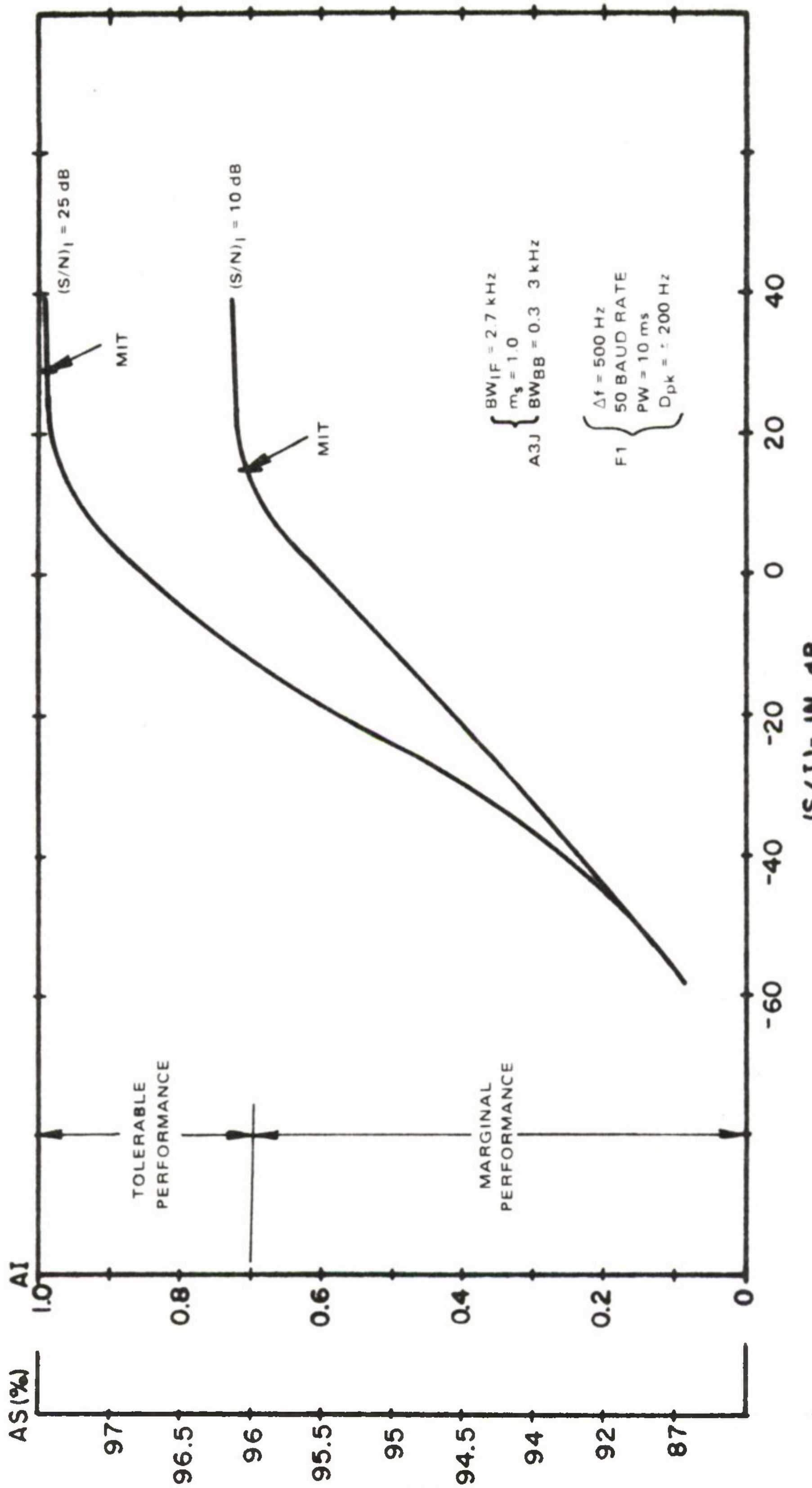


Figure III-34. Performance Degradation Curve For A3J Receiver With F1 Interference (Δf = 500 Hz)

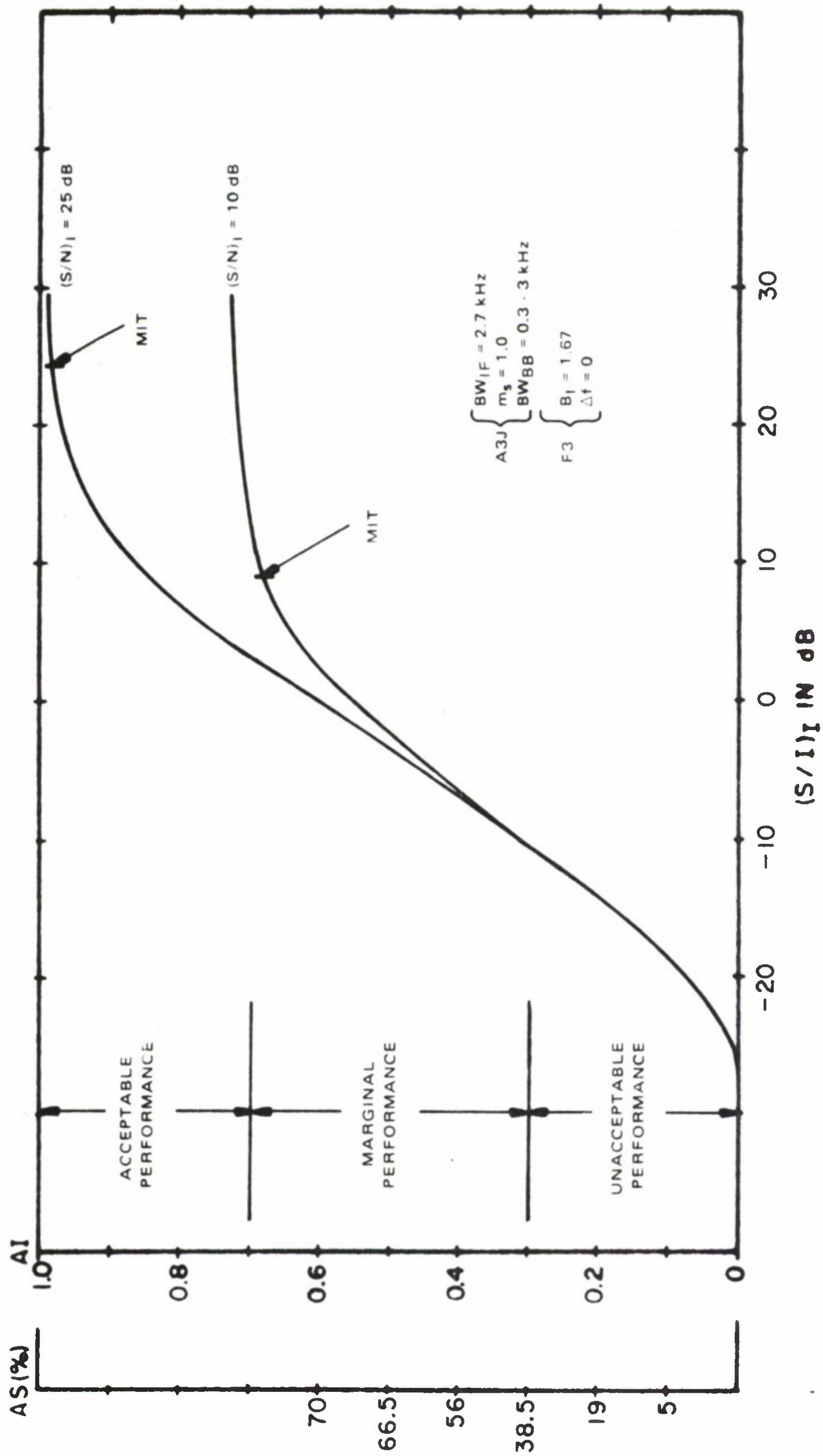


Figure III-35. Performance Degradation Curve For A3J Receiver With F3 Interference

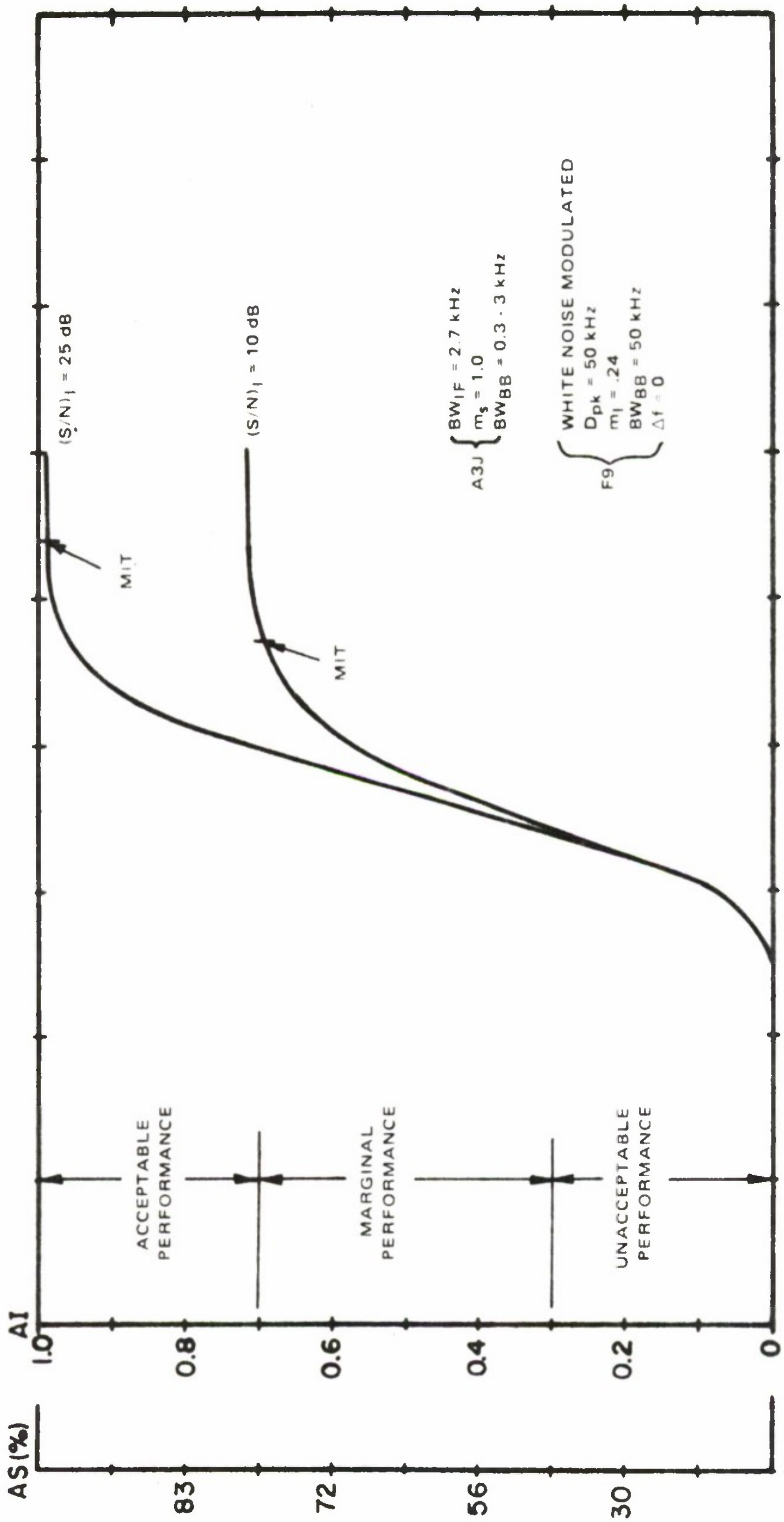


Figure III-36. Performance Degradation Curve For A3J Receiver With F9 Interference

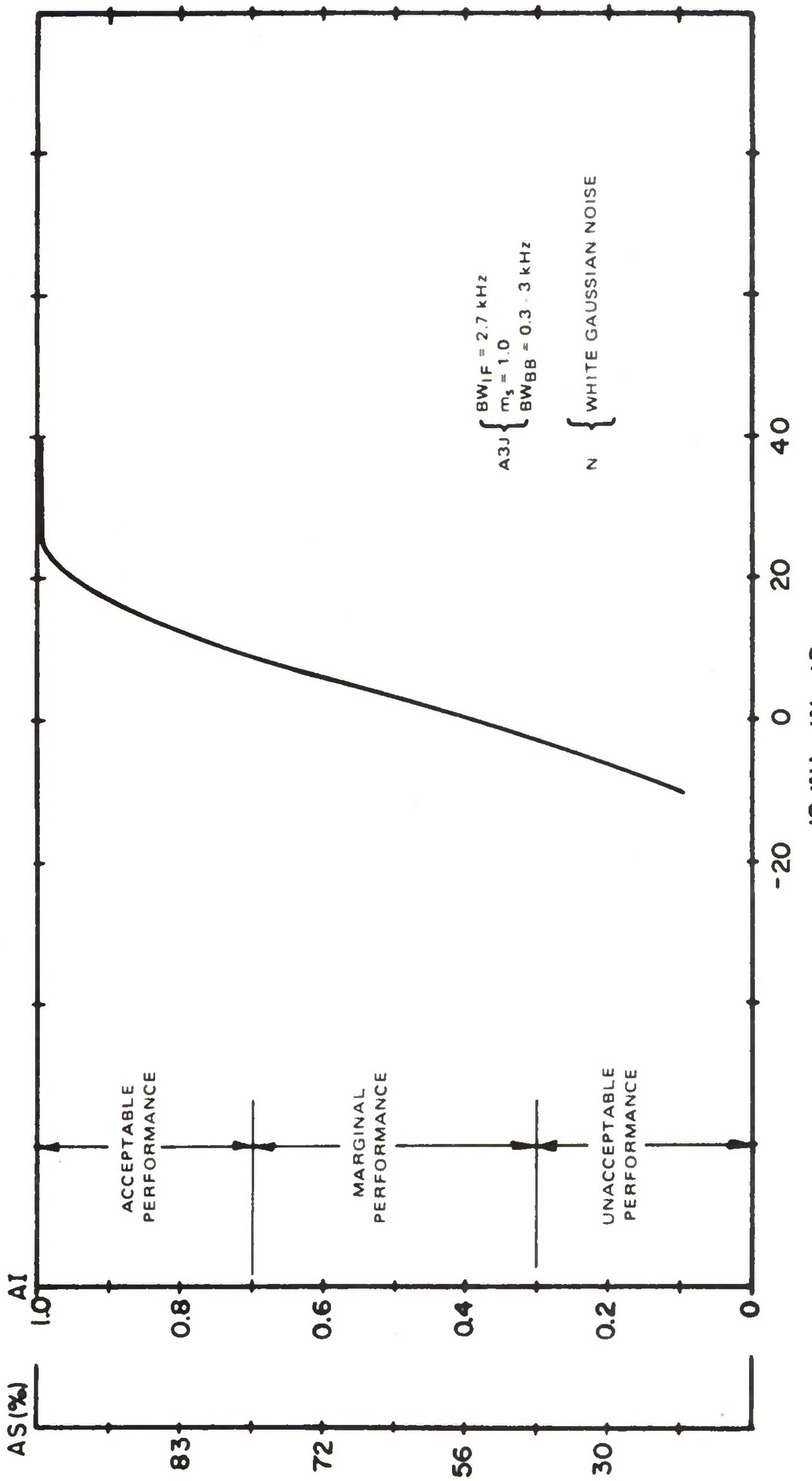


Figure III-37. Performance Degradation Curve For A3J Receiver With Noise

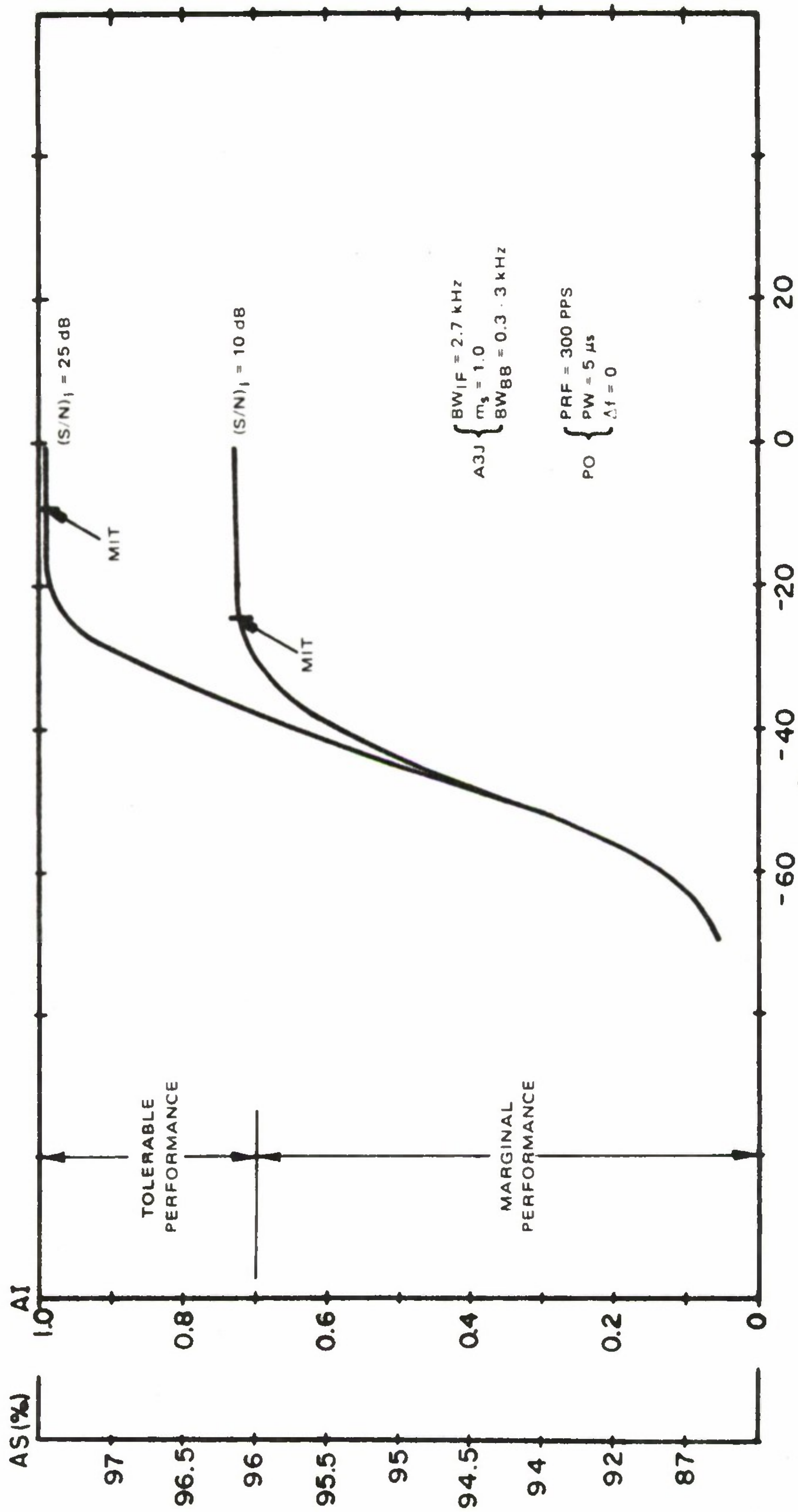


Figure III-38. Performance Degradation Curve For A3J Receiver With PO Interference

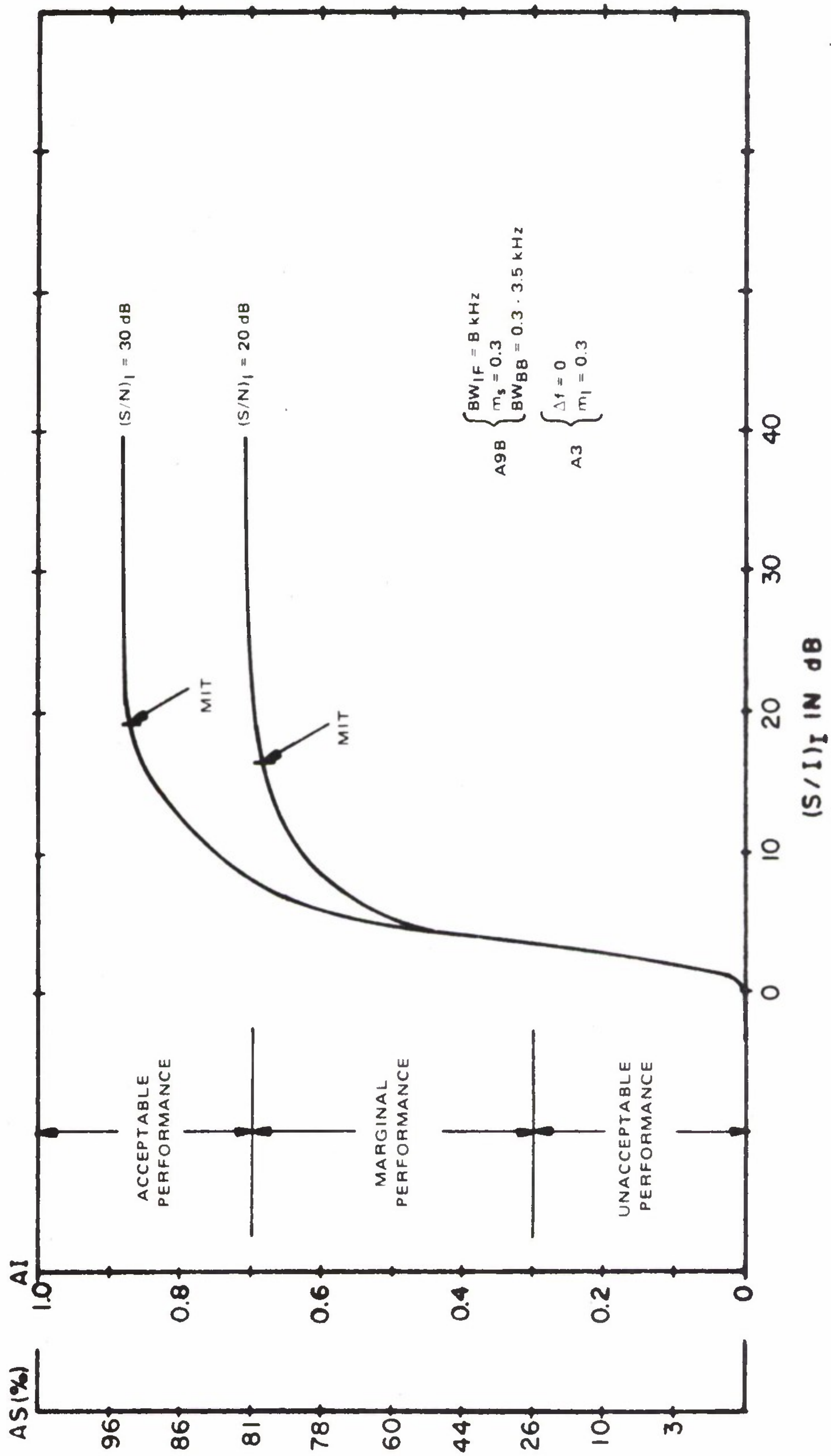


Figure III-39. Performance Degradation Curve For A9B Receiver With A3 Interference (Δf = 0 Hz)

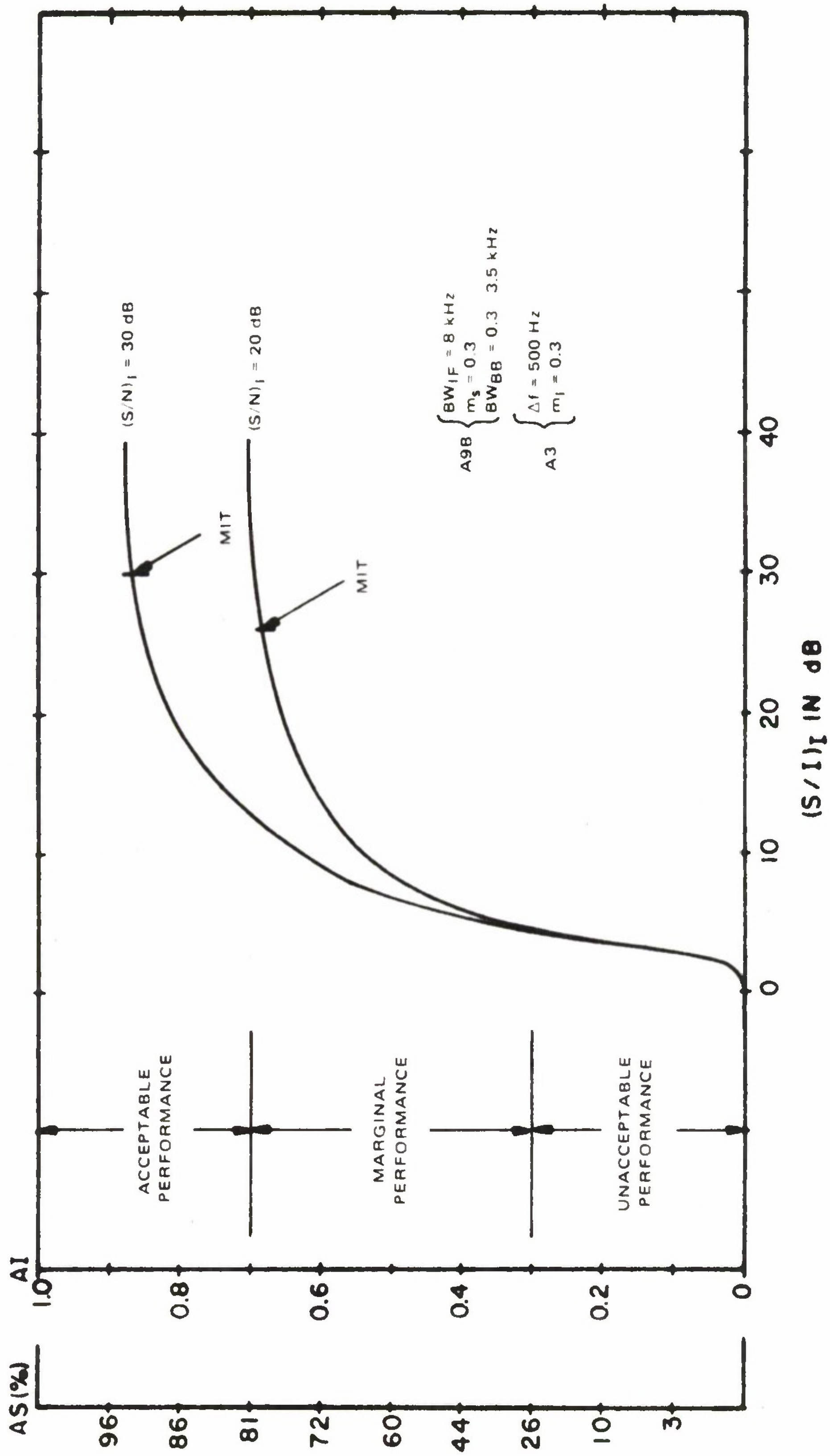


Figure III-40. Performance Degradation Curve For A9B Receiver With A3 Interference (Δf = 500 Hz)

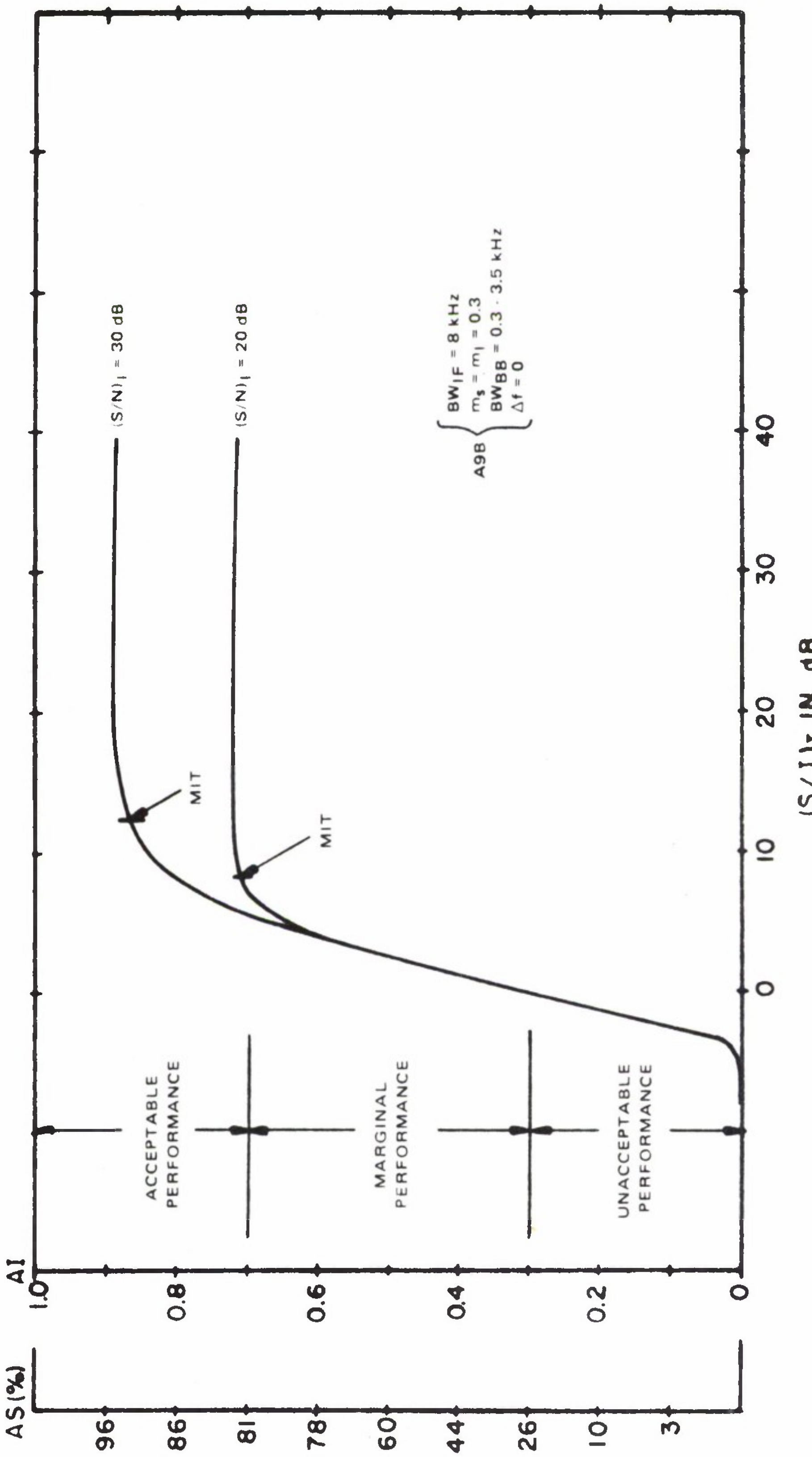


Figure III-41. Performance Degradation Curve For A9B Receiver With A9B Interference (Δf = 0 Hz)

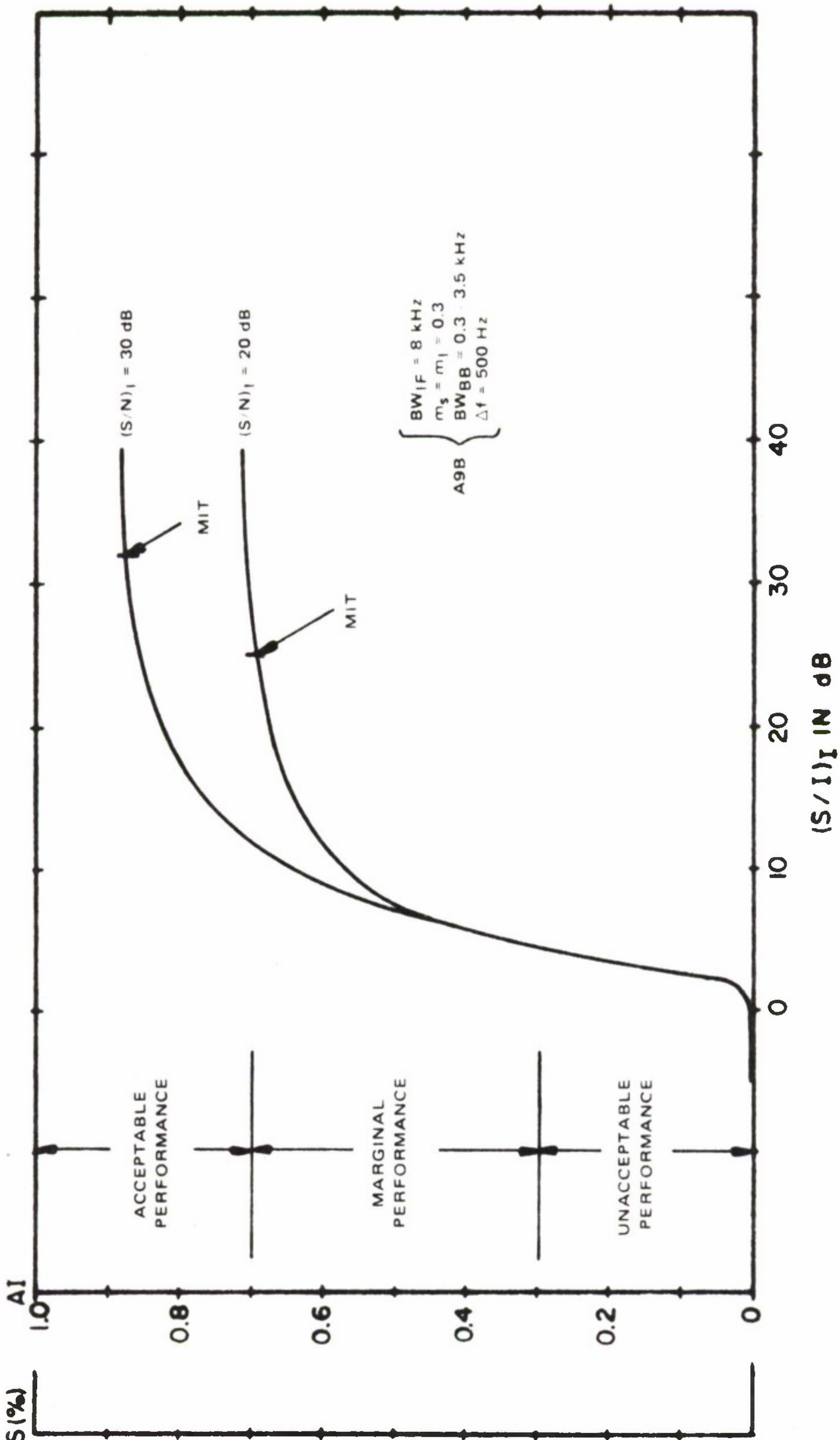


Figure III-42. Performance Degradation Curve For A9B Receiver With A9B Interference (Δf = 500 Hz)

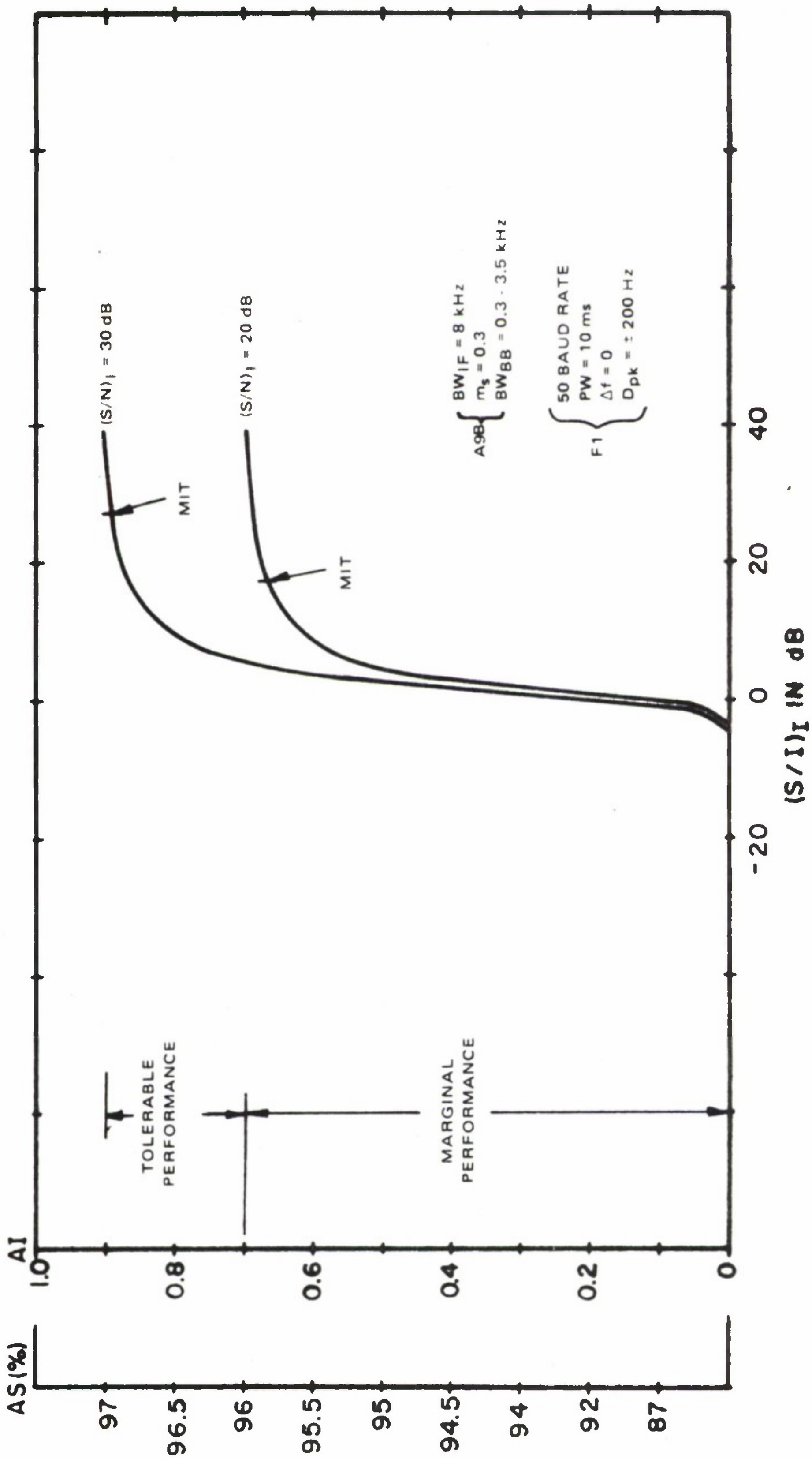


Figure III-43. Performance Degradation Curve For A9B Receiver With F1 Interference (Δf = 0 Hz)

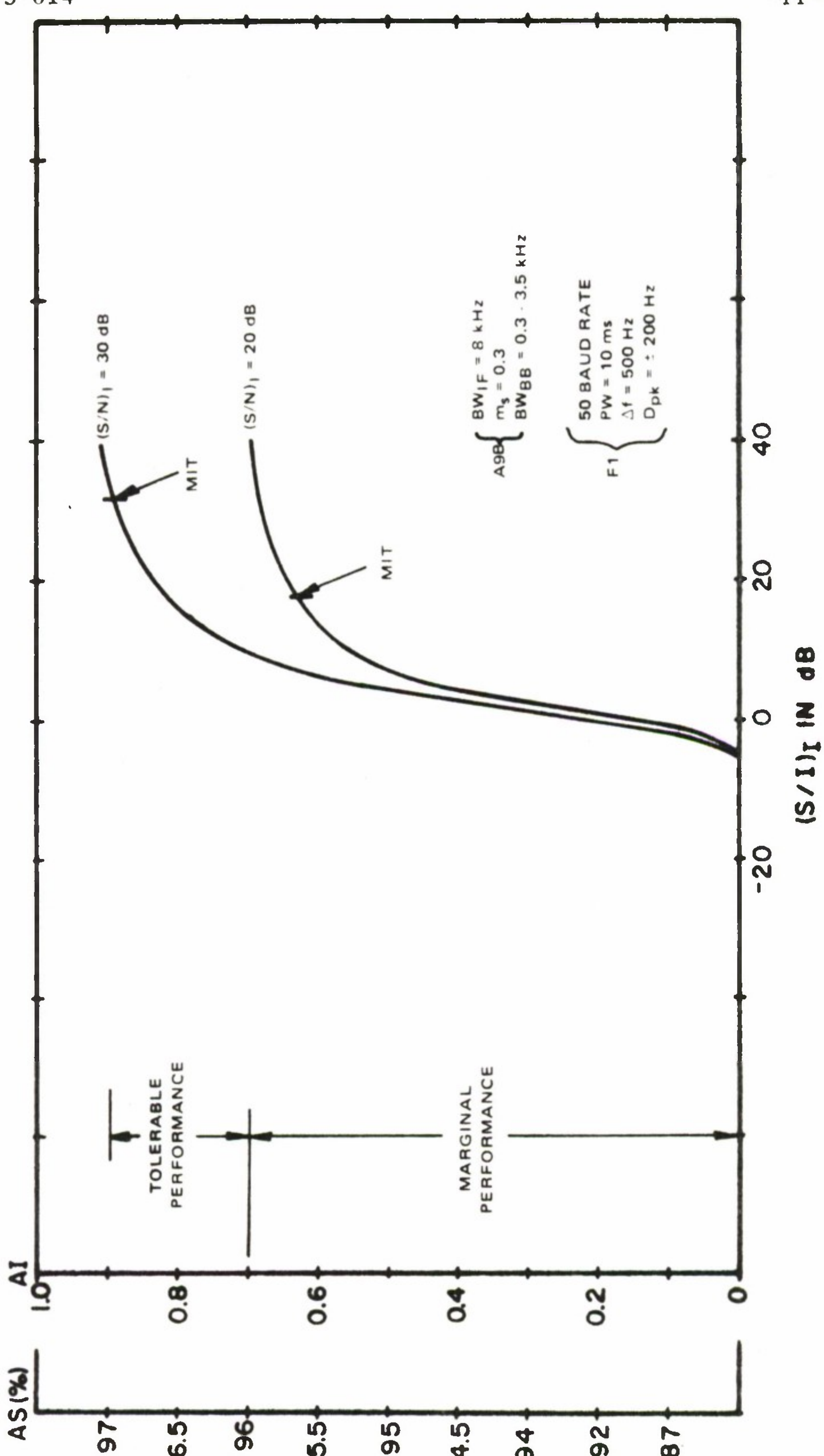


Figure III-44. Performance Degradation Curve For A9B Receiver With F1 Interference (Δf = 500 Hz)

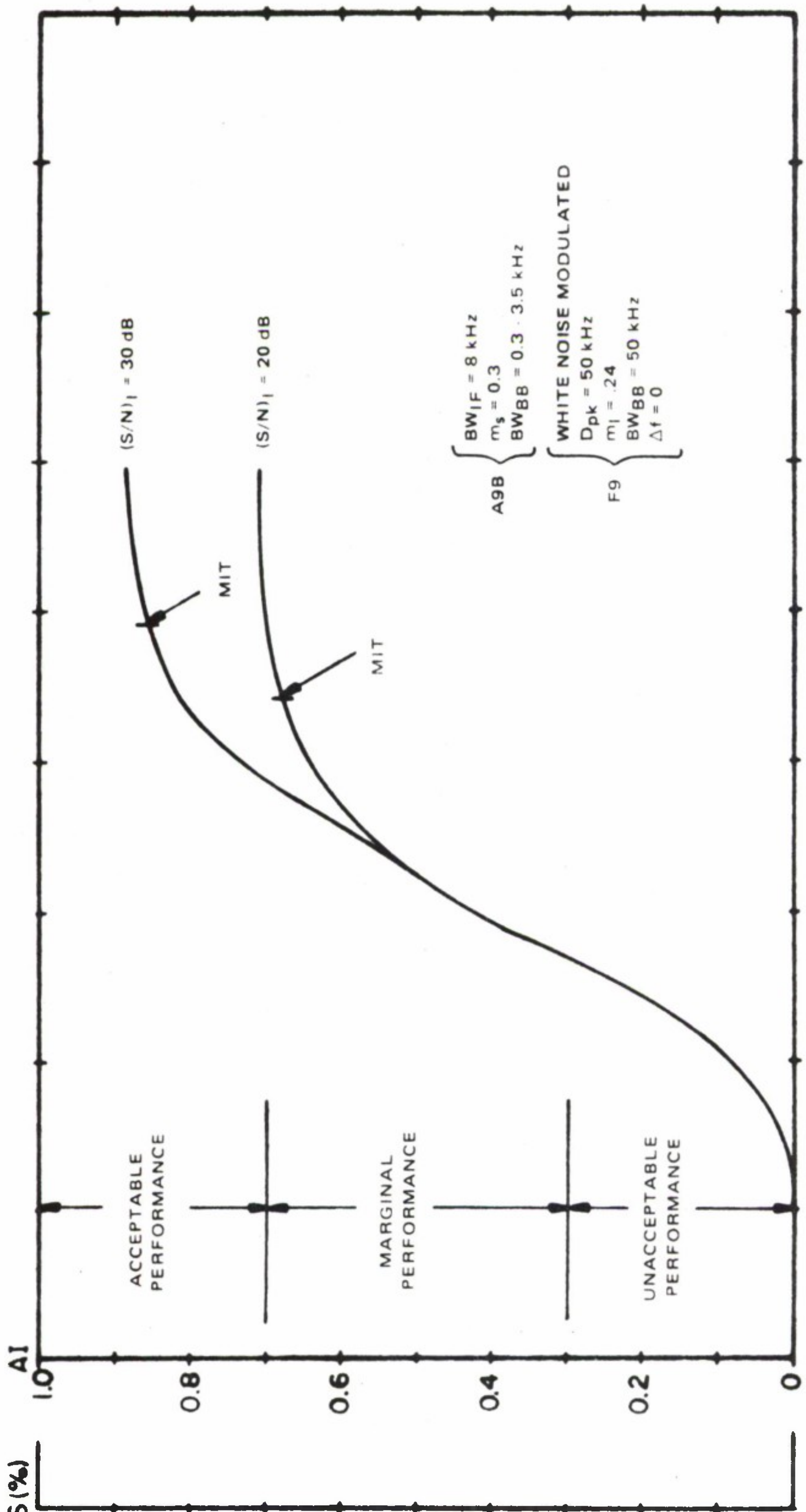


Figure III-45. Performance Degradation Curve For A9B Receiver With F9 Interference

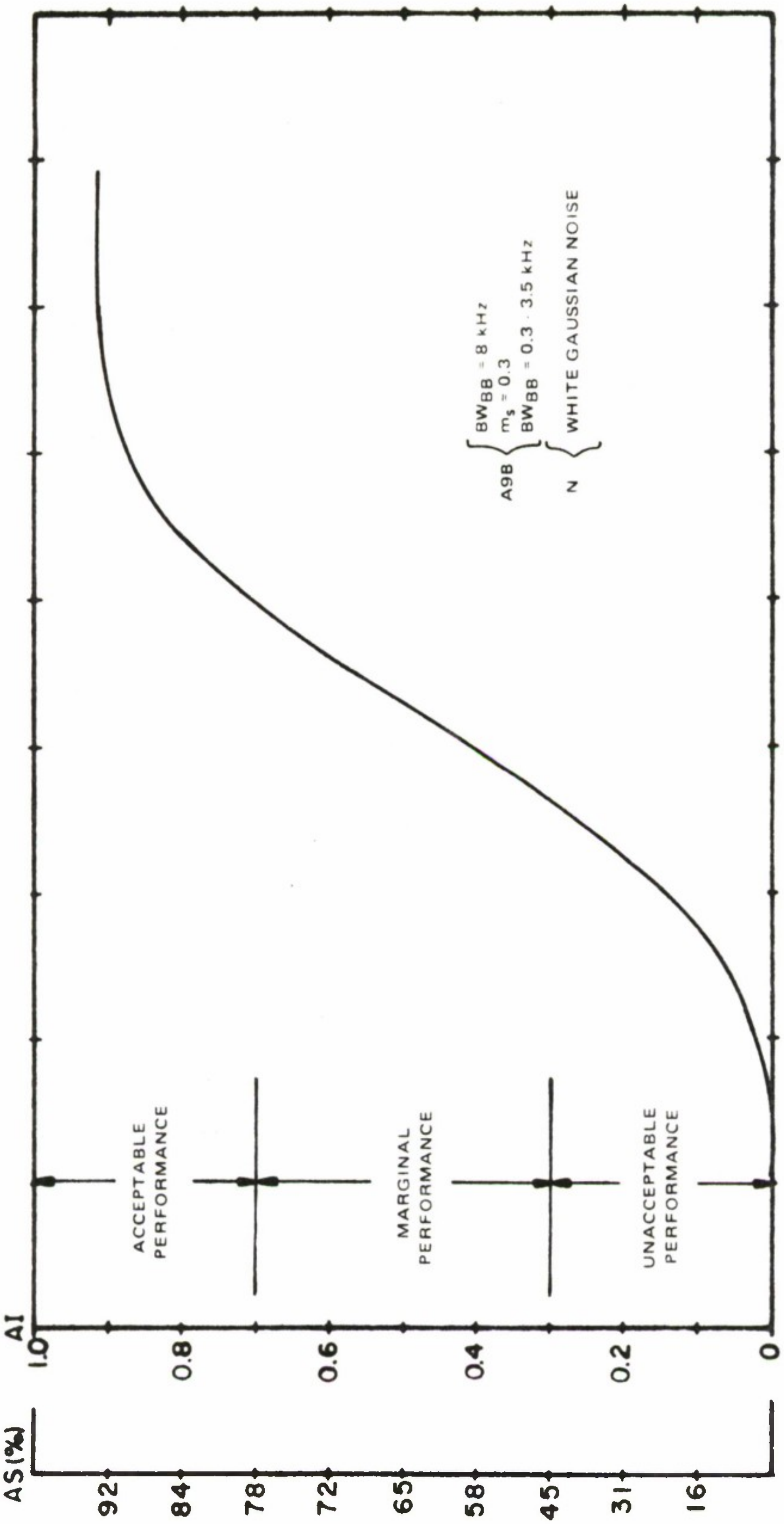


Figure III-46. Performance Degradation Curve For A9B Receiver With Noise

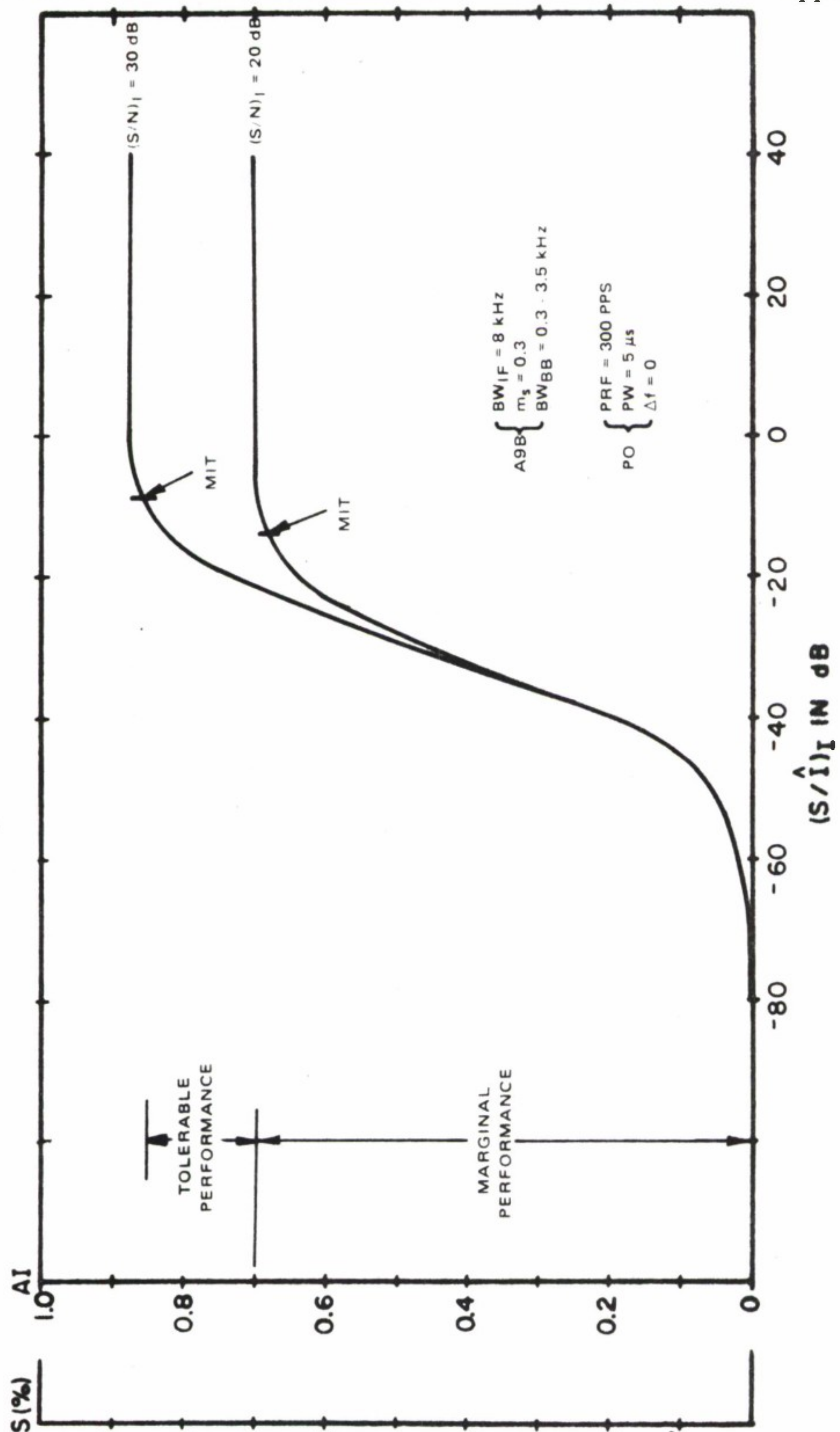


Figure III-47. Performance Degradation Curve For A9B Receiver With PO Interference

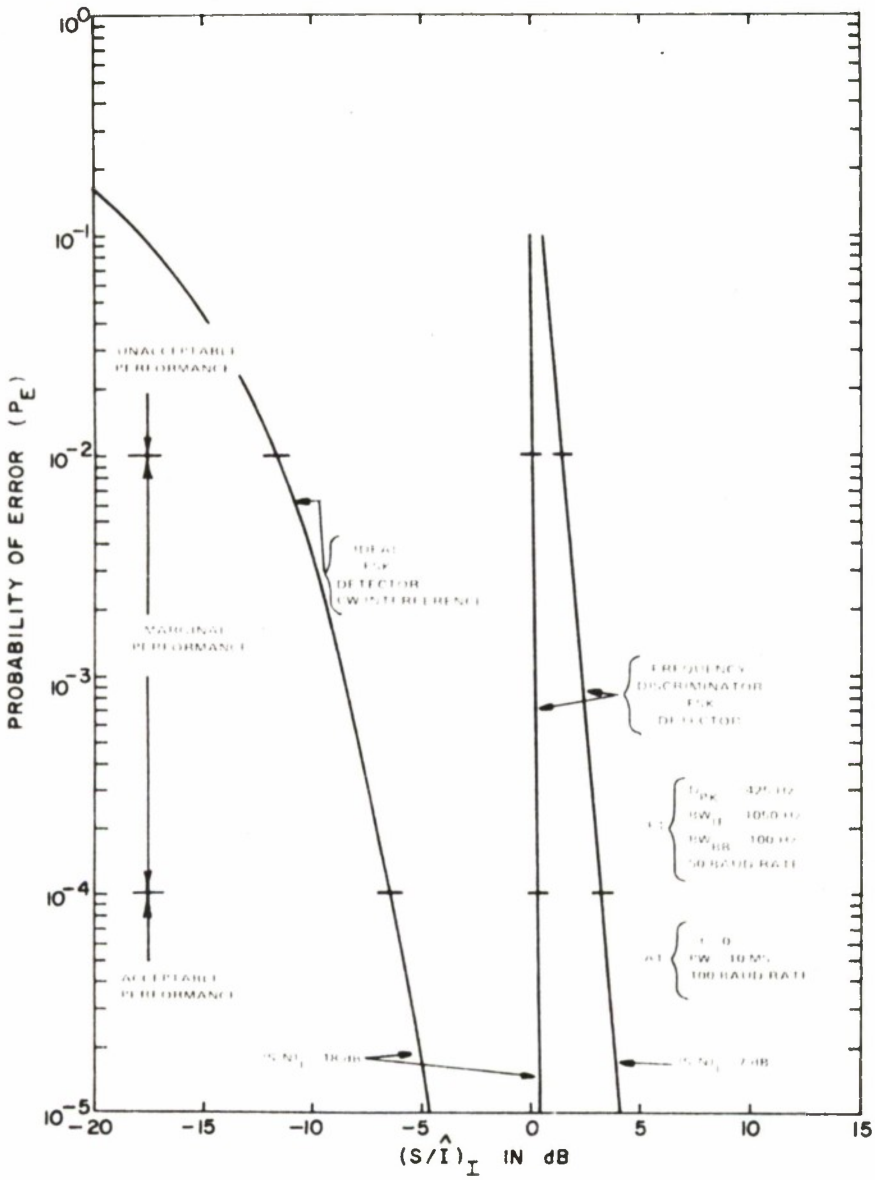


Figure III-48. Performance Degradation Curve For F1 Receiver With A1 Interference

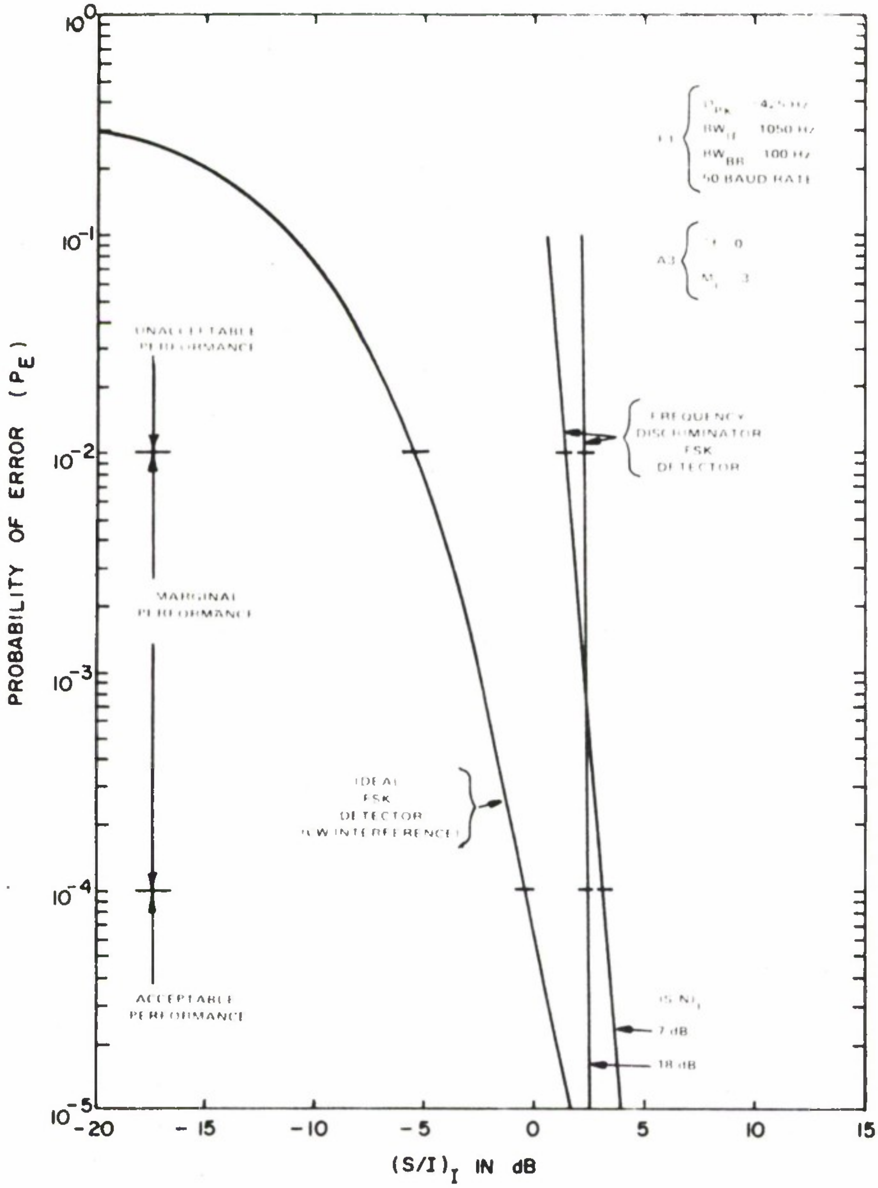


Figure III-49. Performance Degradation Curve For F1 Receiver With A3 Interference

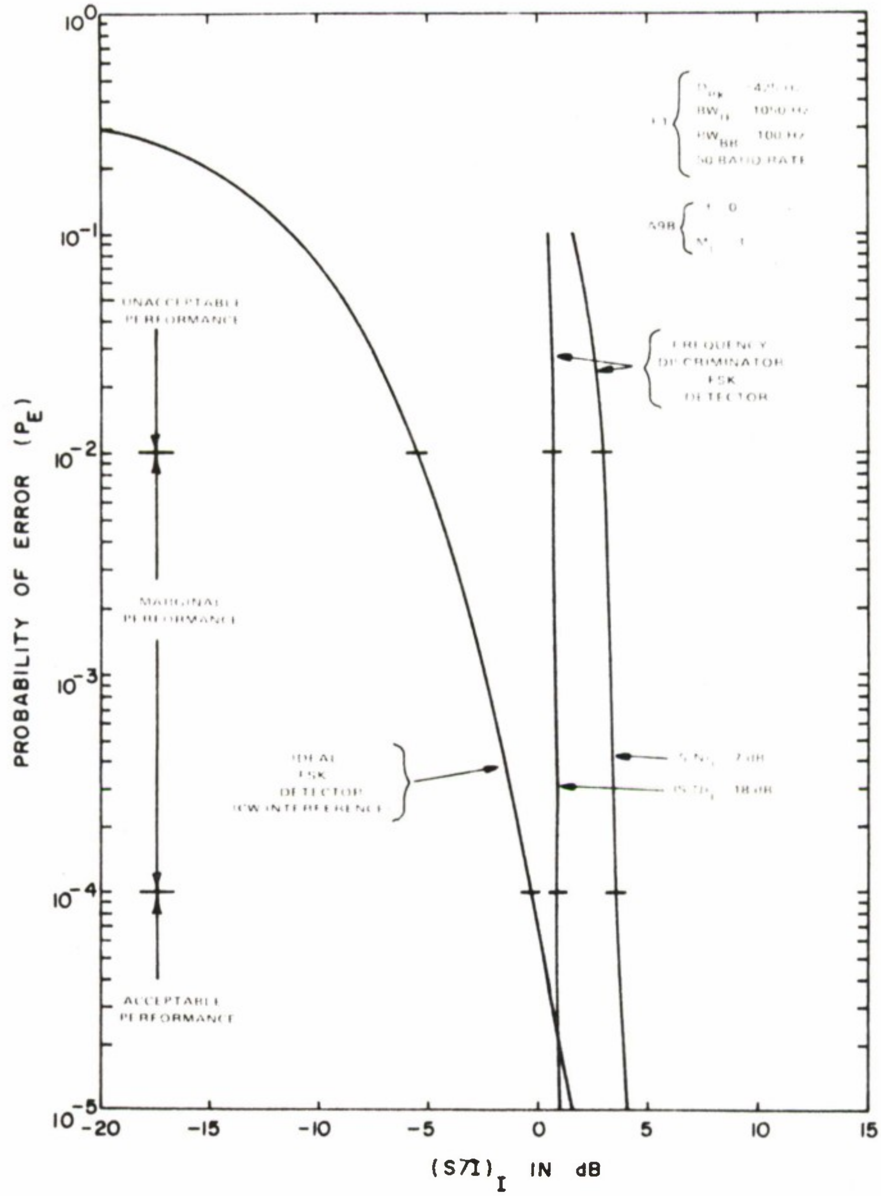


Figure III-50. Performance Degradation Curve For F1 Receiver With A9B Interference

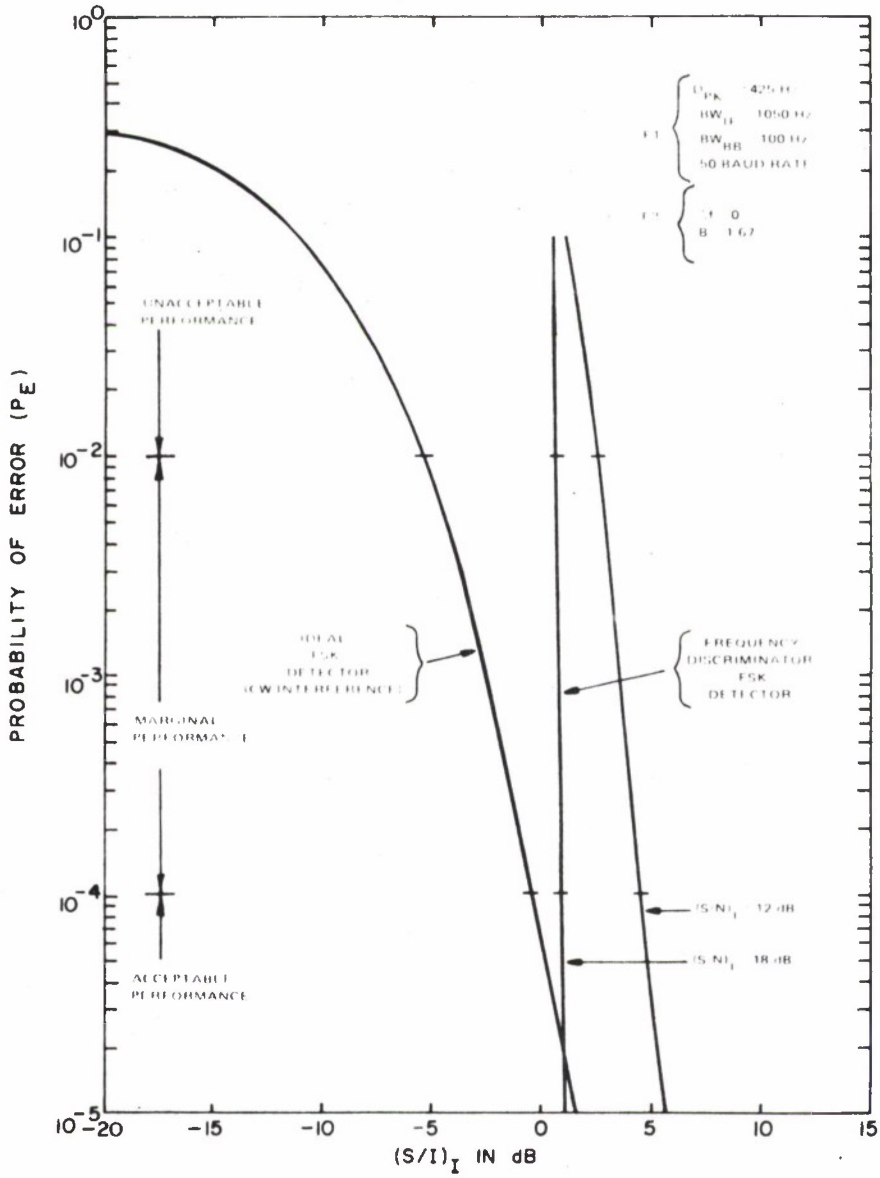


Figure III-51. Performance Degradation Curve For F1 Receiver With F3 Interference

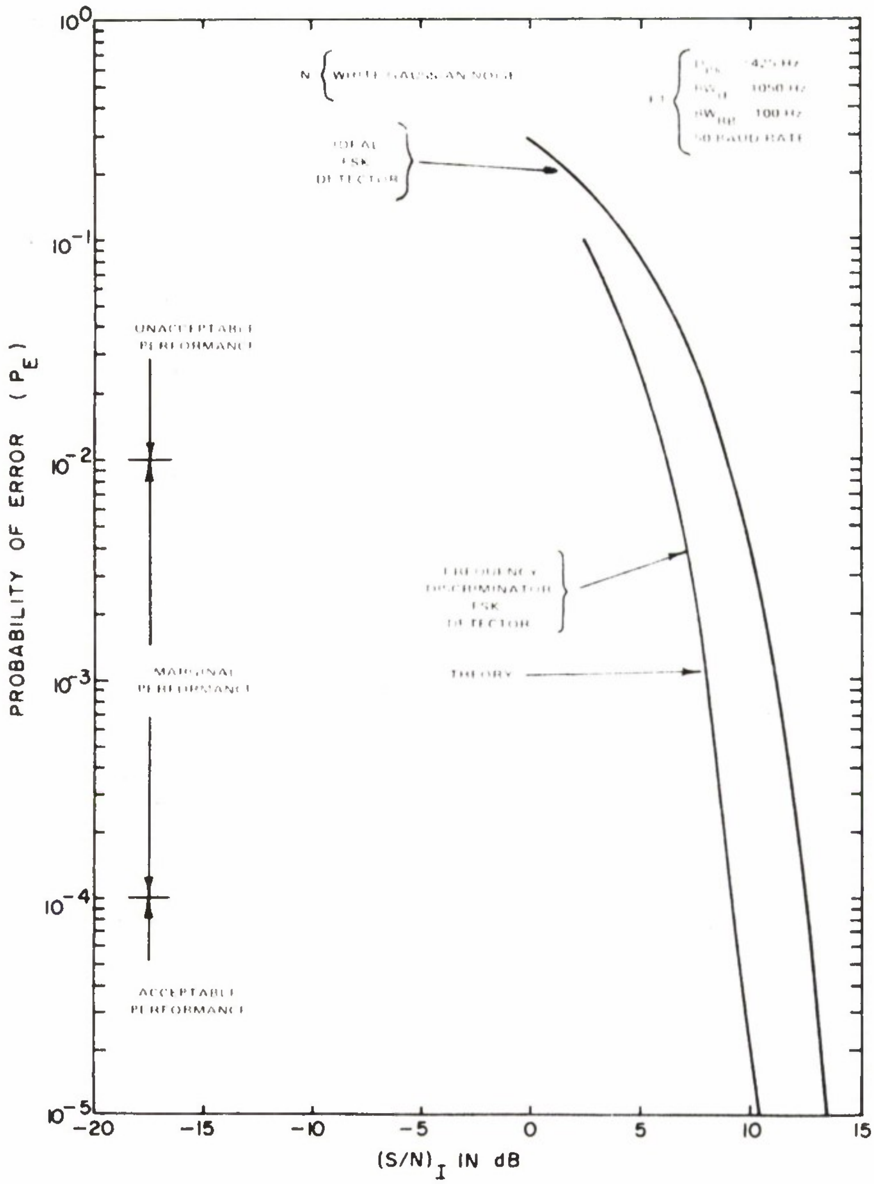


Figure III-52. Performance Degradation Curve For F1 Receiver With Noise

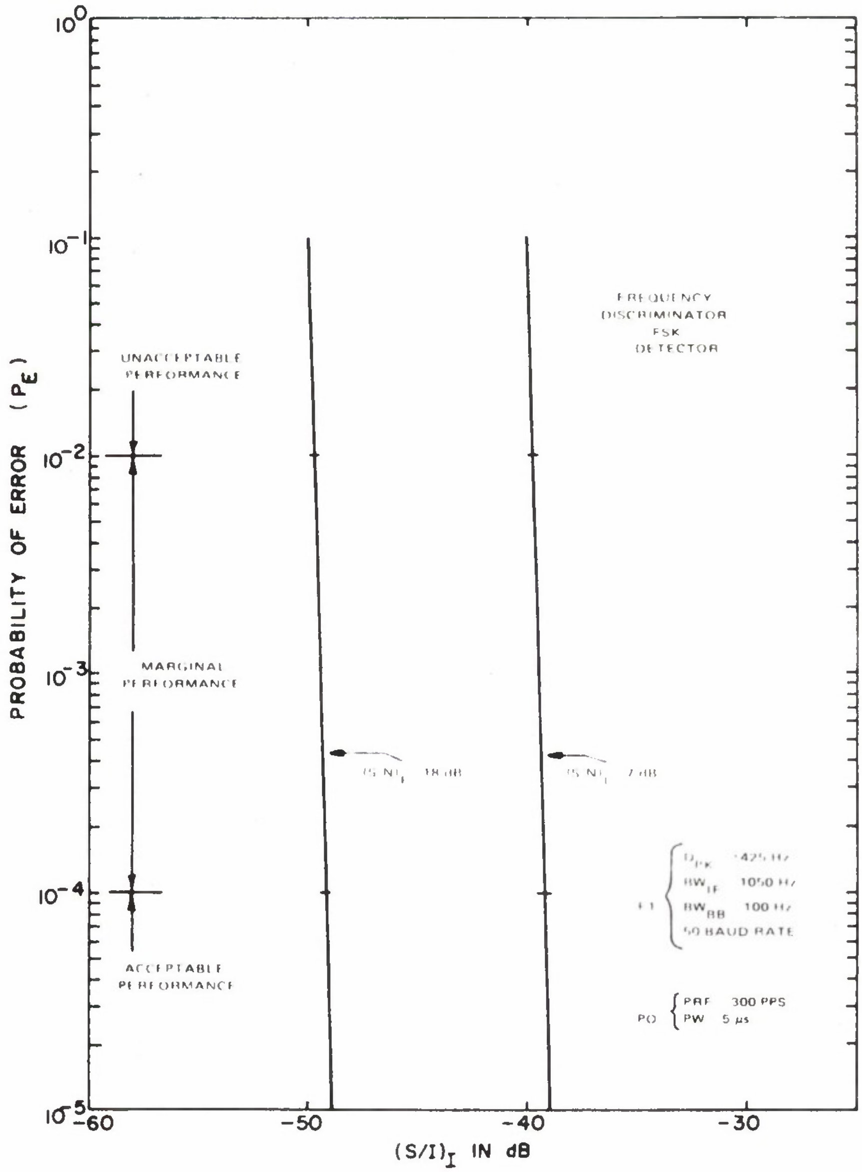


Figure III-53. Performance Degradation Curve For F1 Receiver With PO Interference

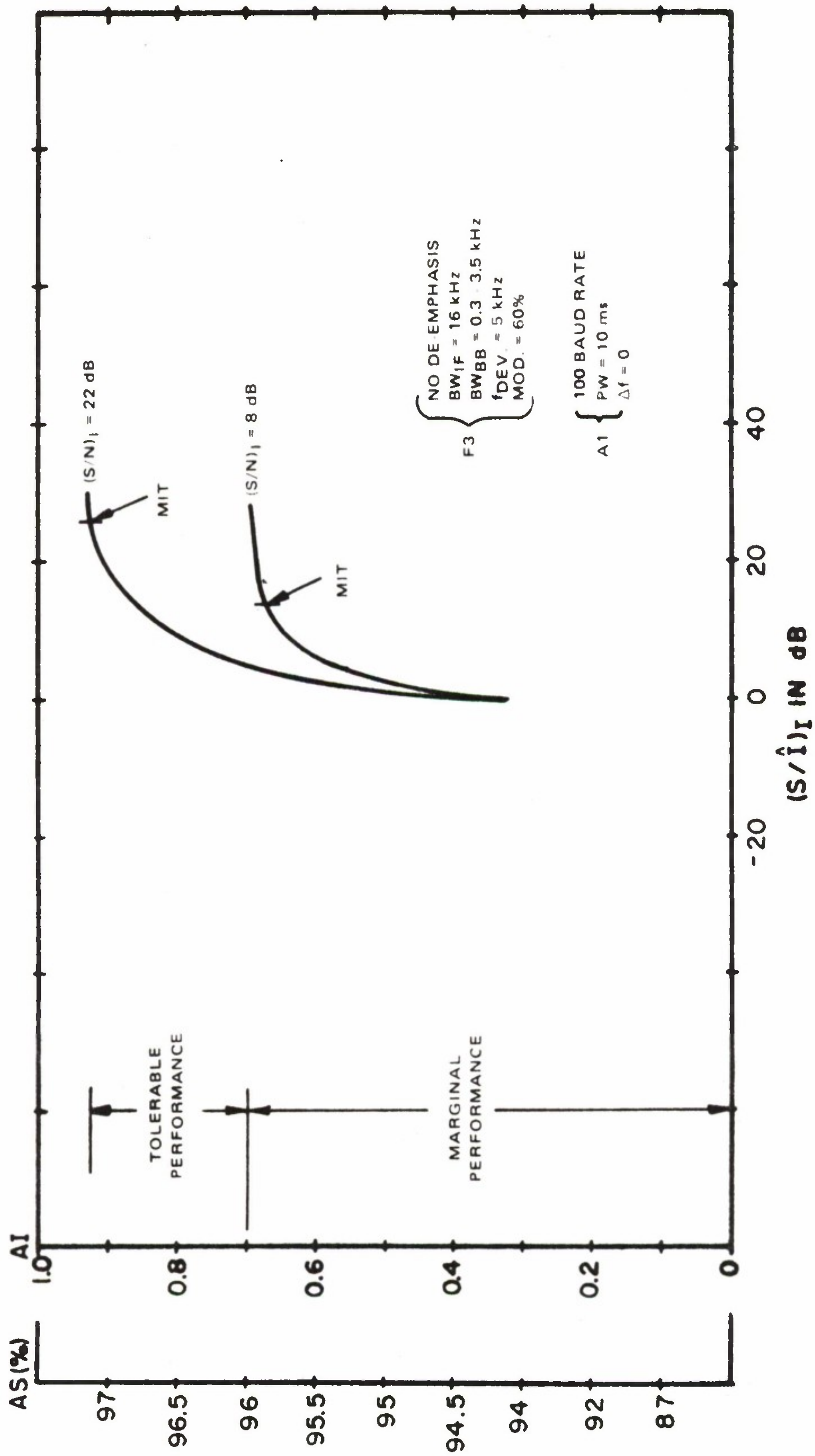


Figure III-54. Performance Degradation Curve For F3 Receiver With A1 Interference

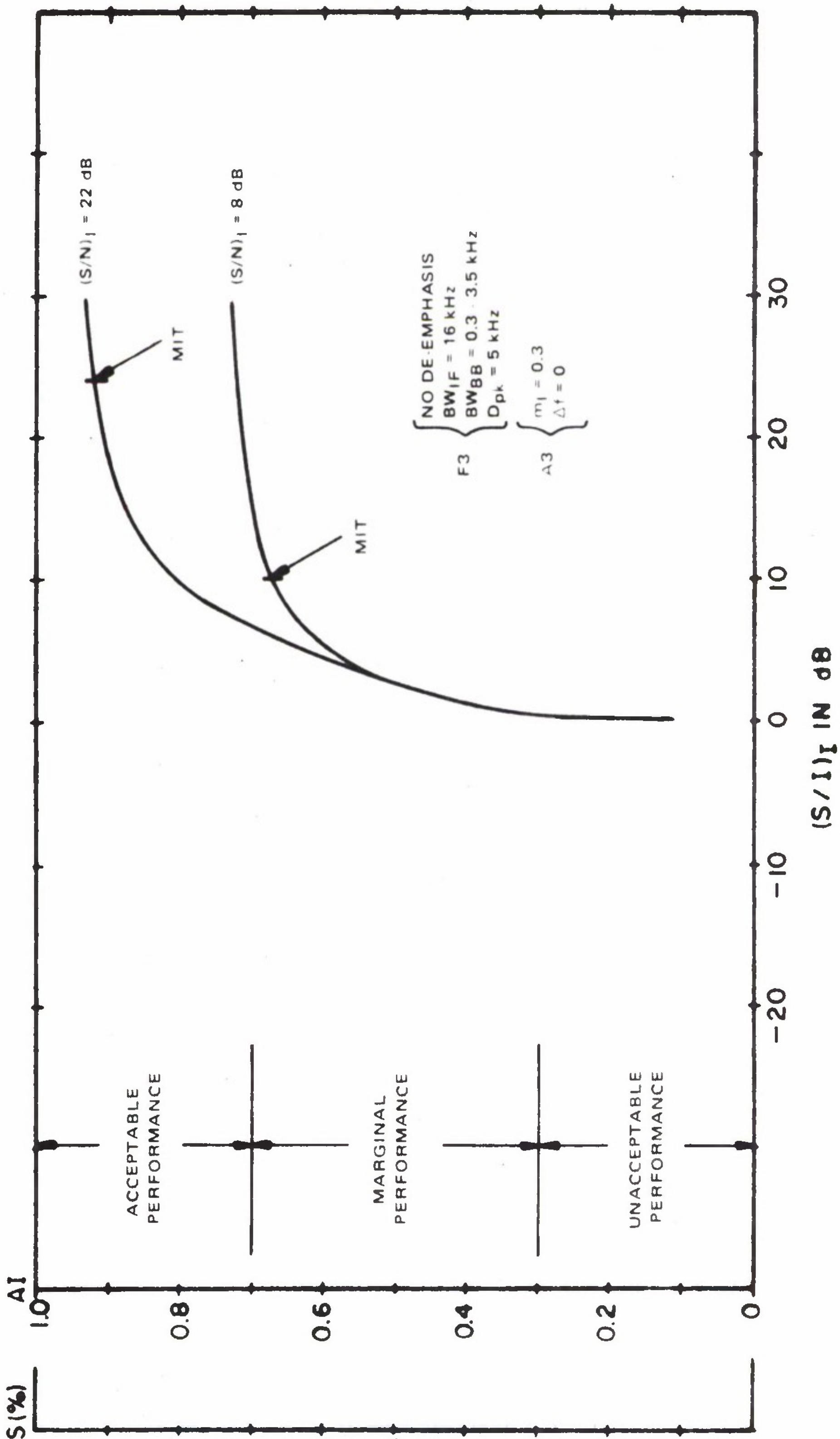


Figure III-55. Performance Degradation Curve For F3 Receiver With A3 Interference (Δf = 0 Hz)

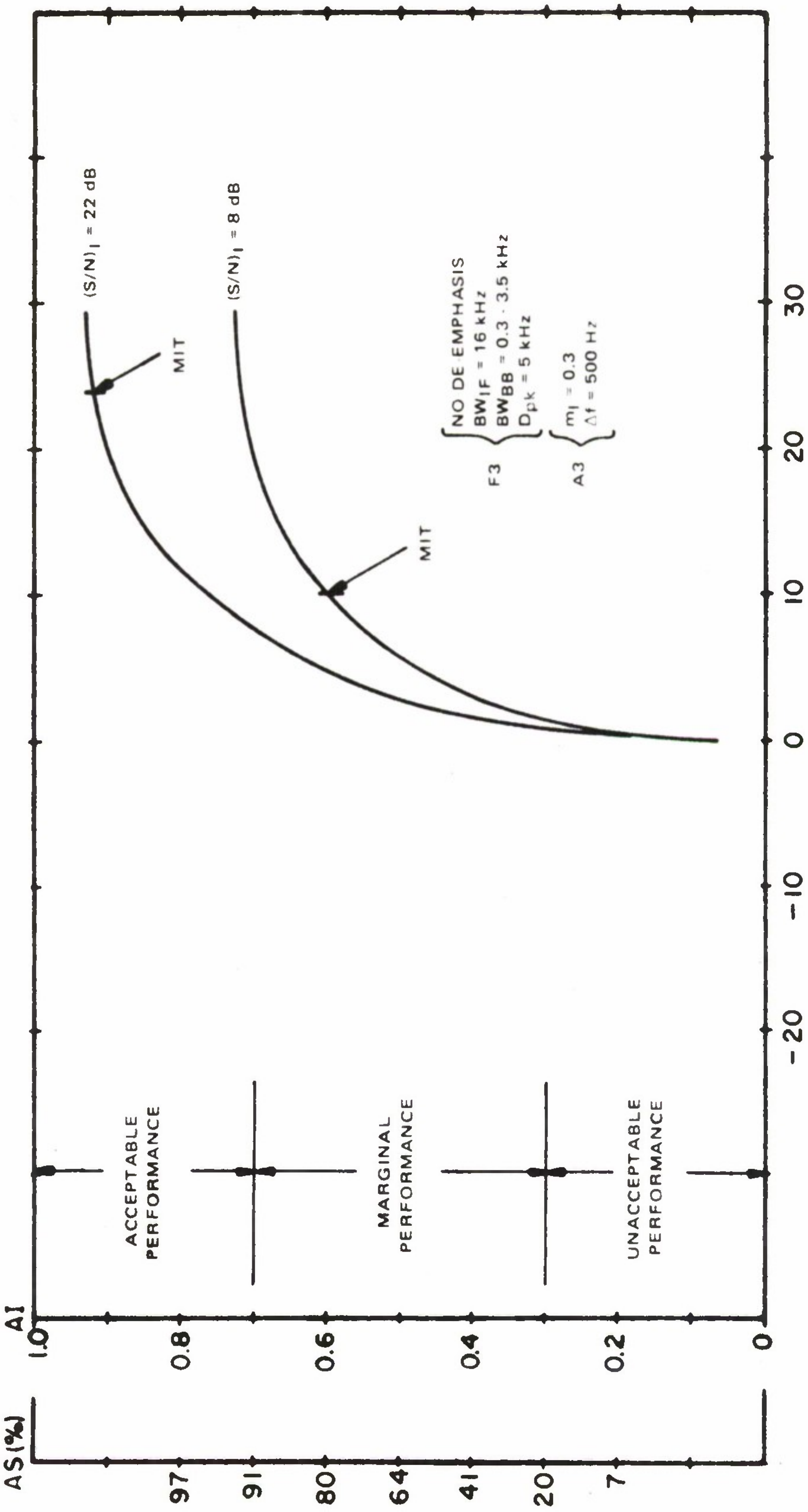


Figure III-56. Performance Degradation Curve For F3 Receiver With A3 Interference (Δf = 500 Hz)

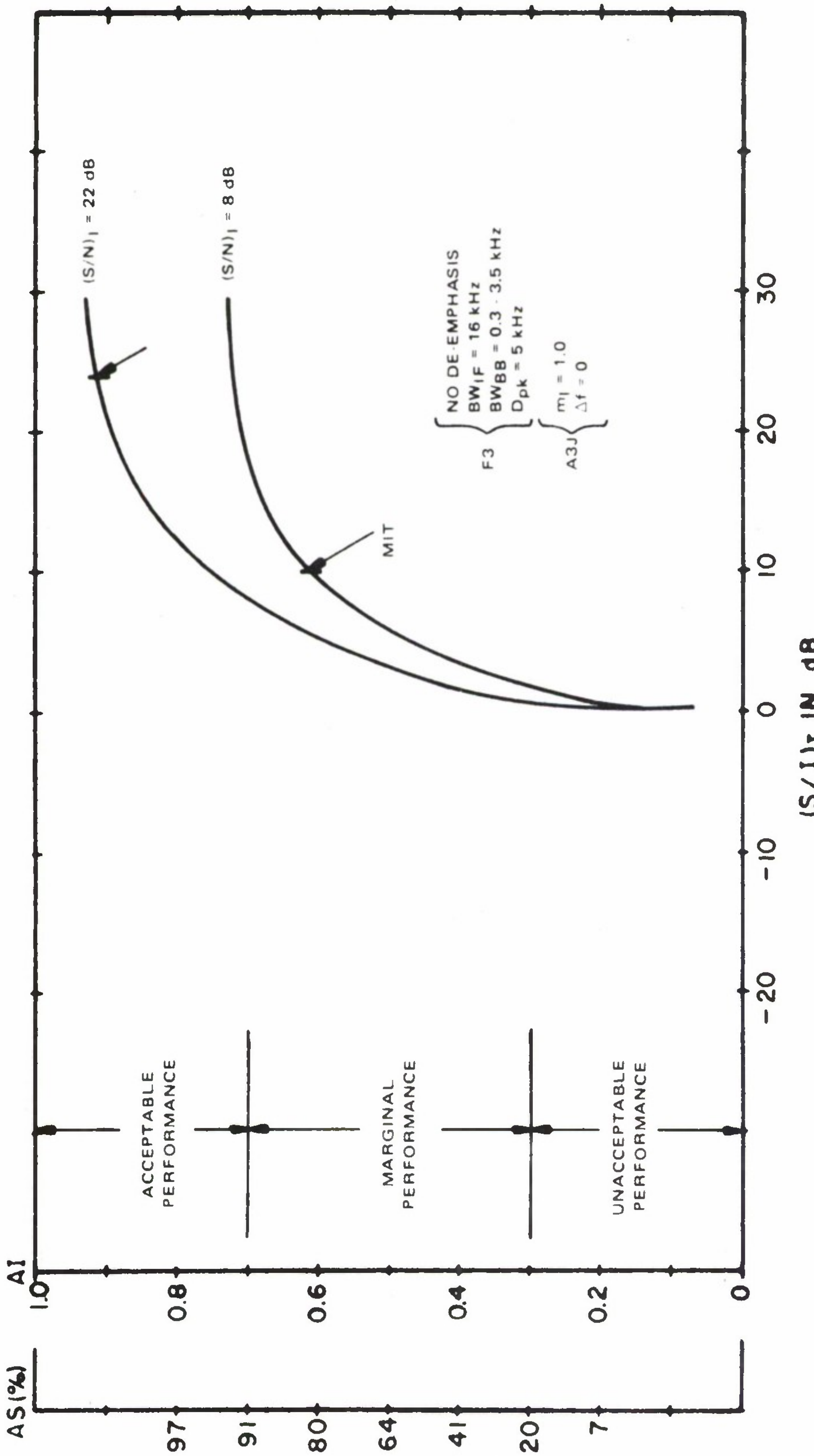


Figure III-57. Performance Degradation Curve For F3 Receiver With A3J Interference

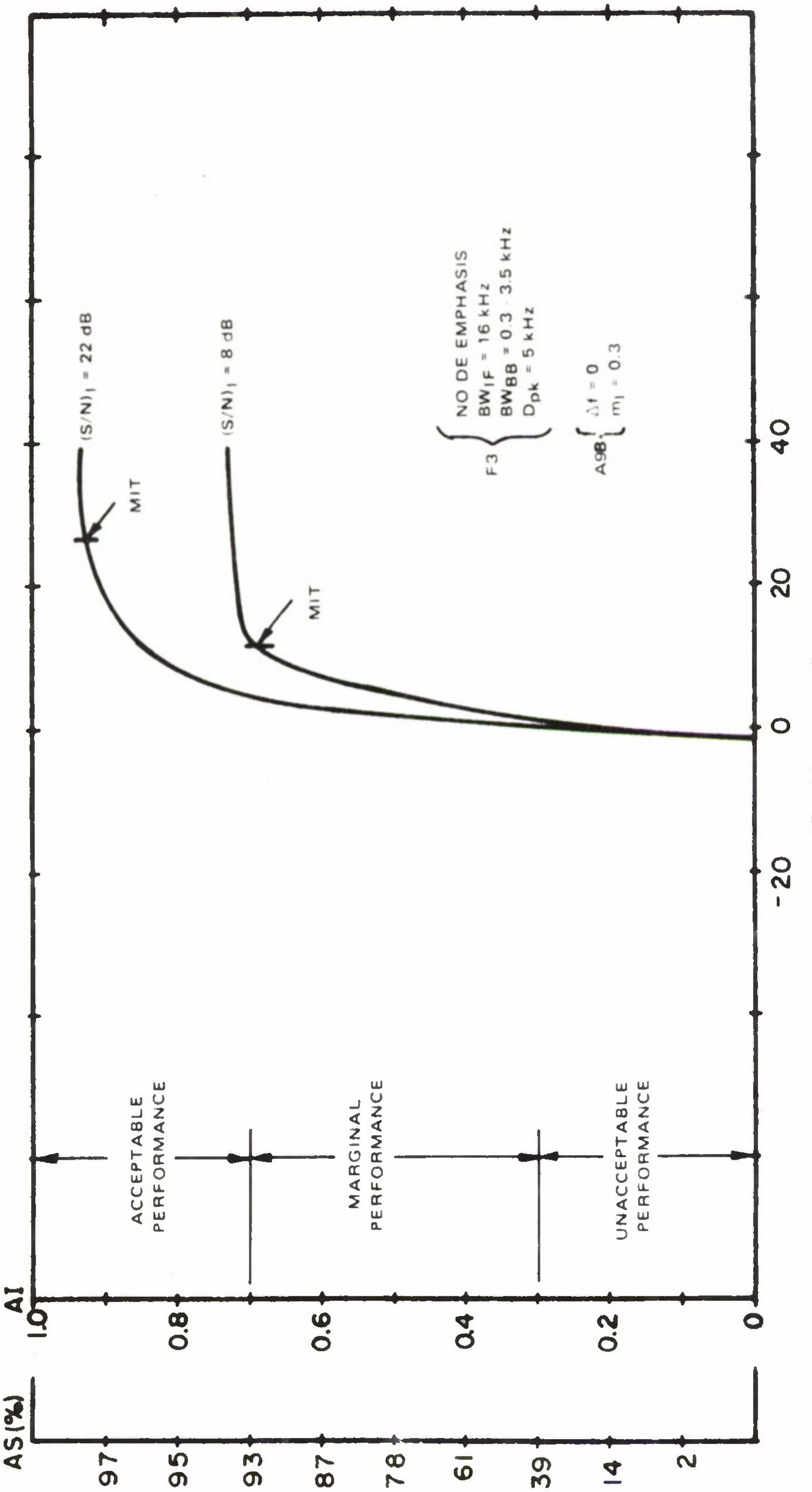


Figure III-58. Performance Degradation Curve For F3 Receiver With A9B Interference

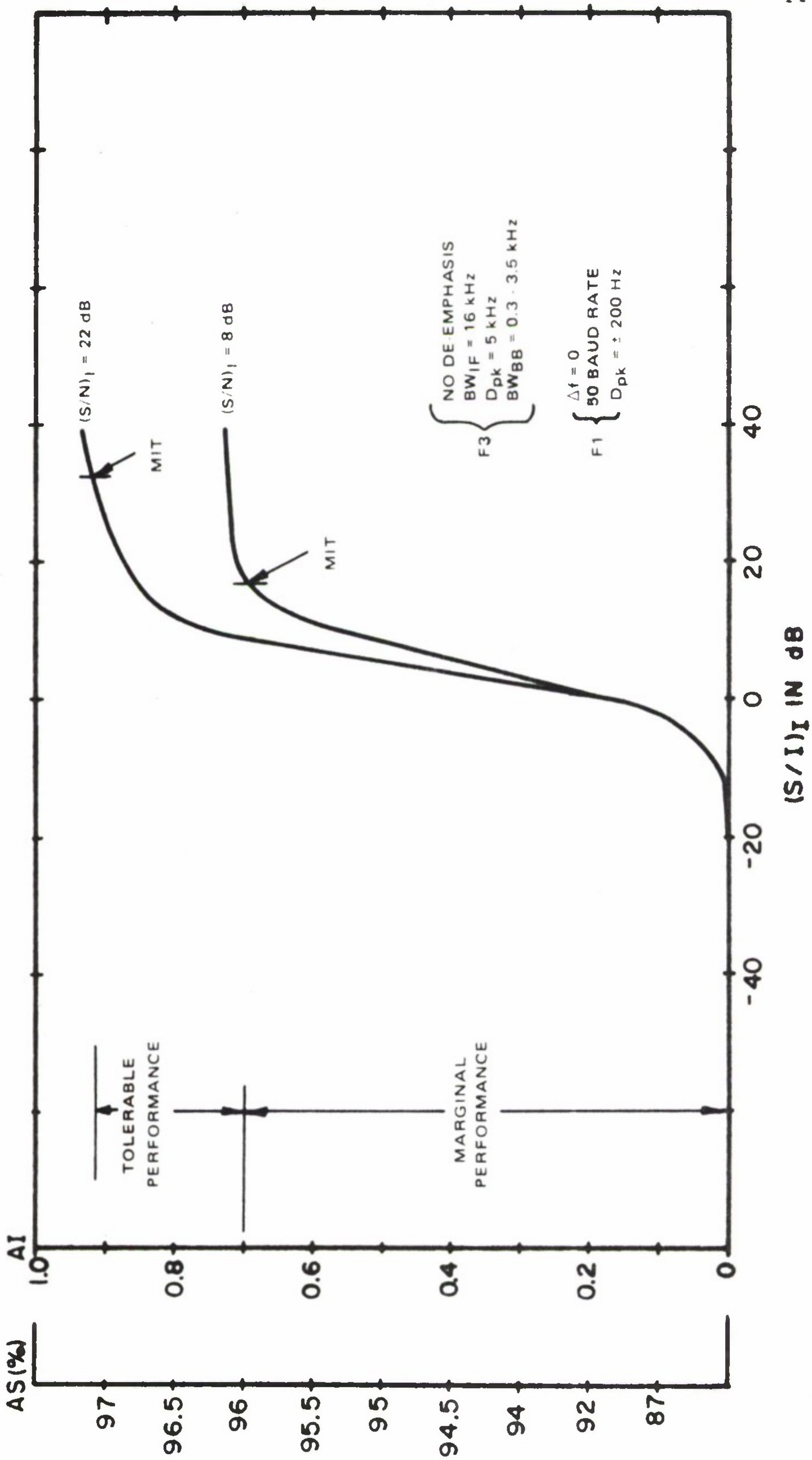


Figure III-59. Performance Degradation Curve For F3 Receiver With F1 Interference ($\Delta f = 0$ Hz)

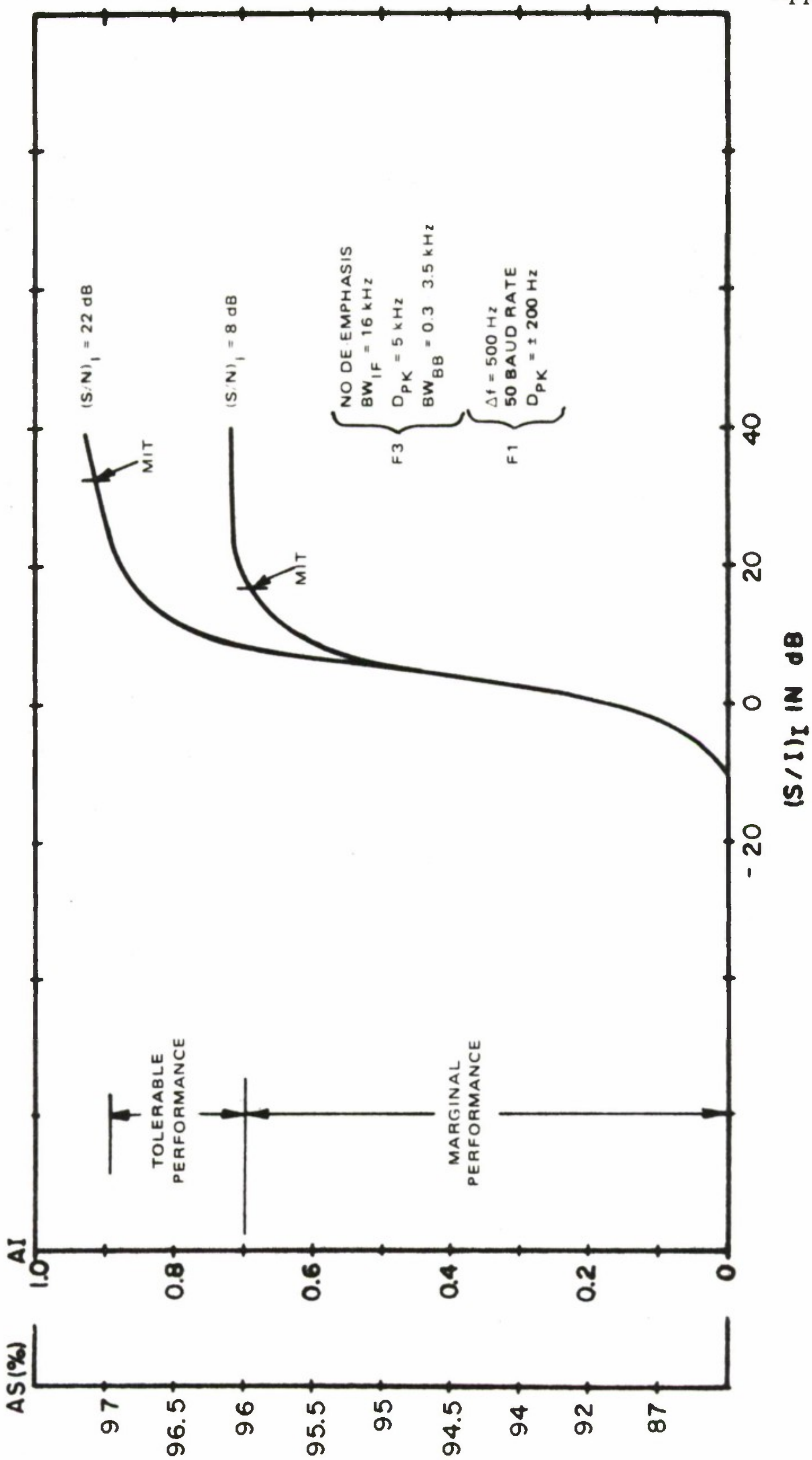


Figure III-60. Performance Degradation Curve For F3 Receiver With F1 Interference (Δf = 500 Hz)

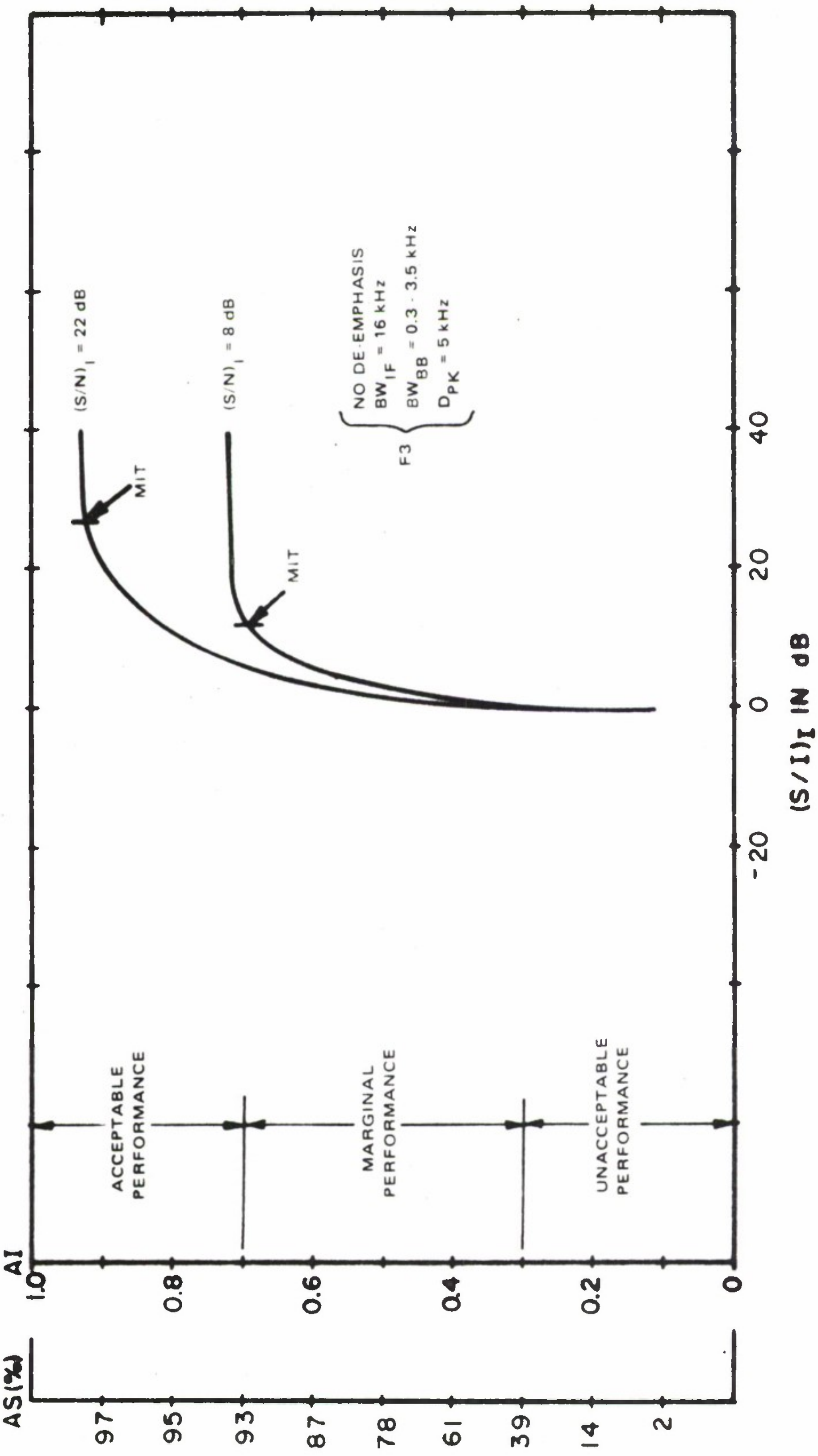


Figure III-61. Performance Degradation Curve For F3 Receiver With F3 Interference

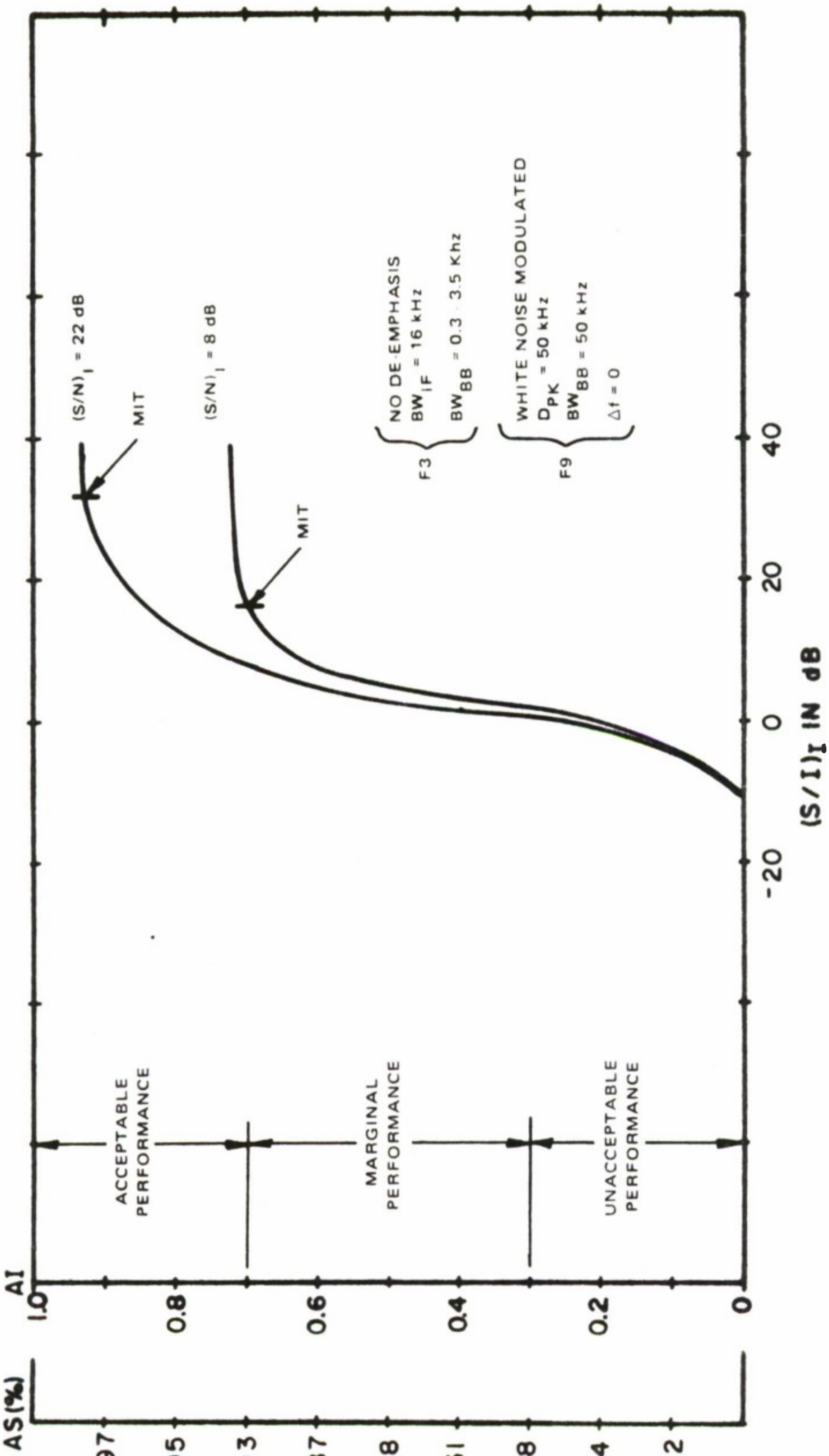


Figure III-62. Performance Degradation Curve For F3 Receiver With F9 Interference

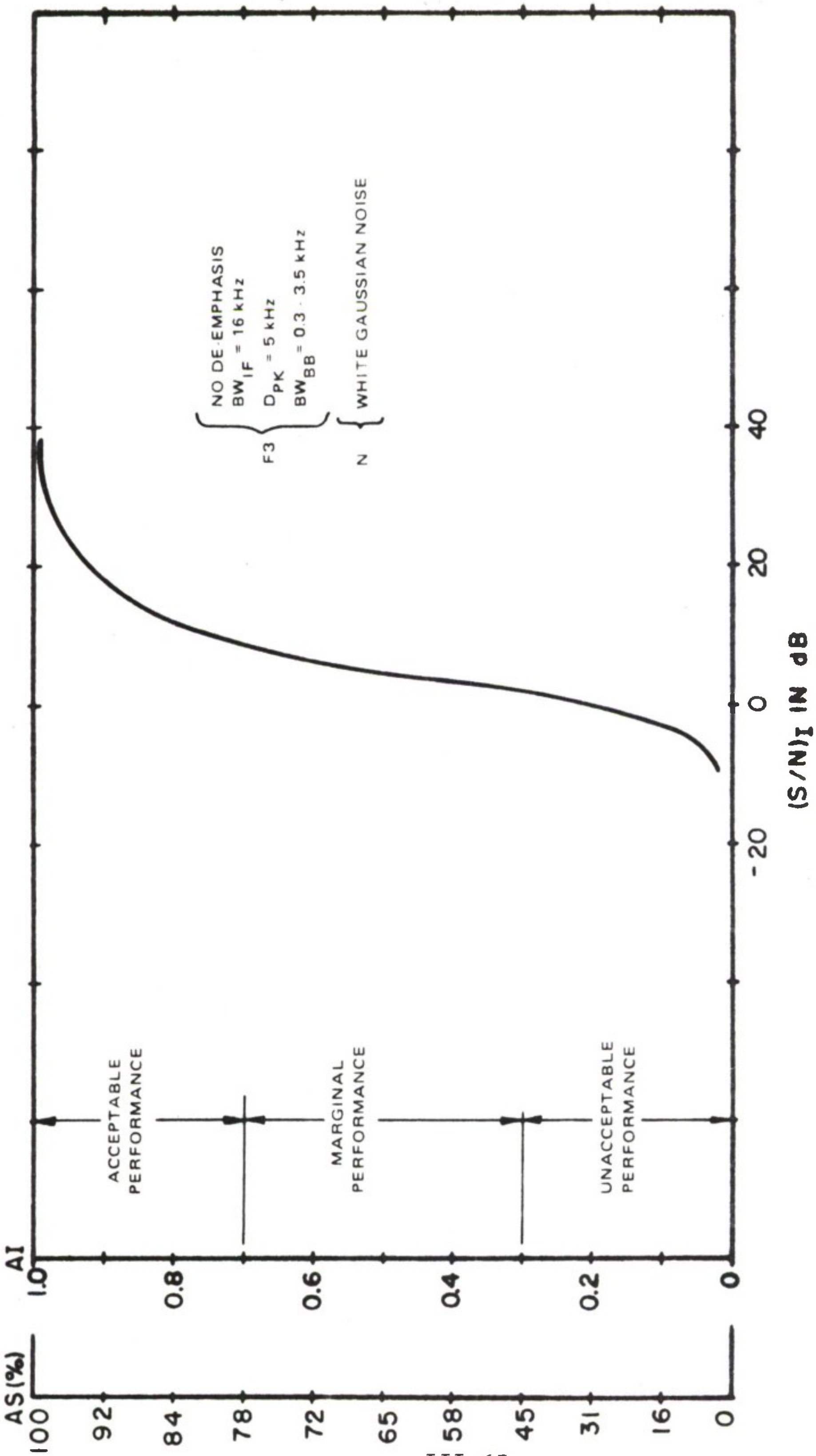


Figure III-63. Performance Degradation Curve For F3 Receiver With Noise

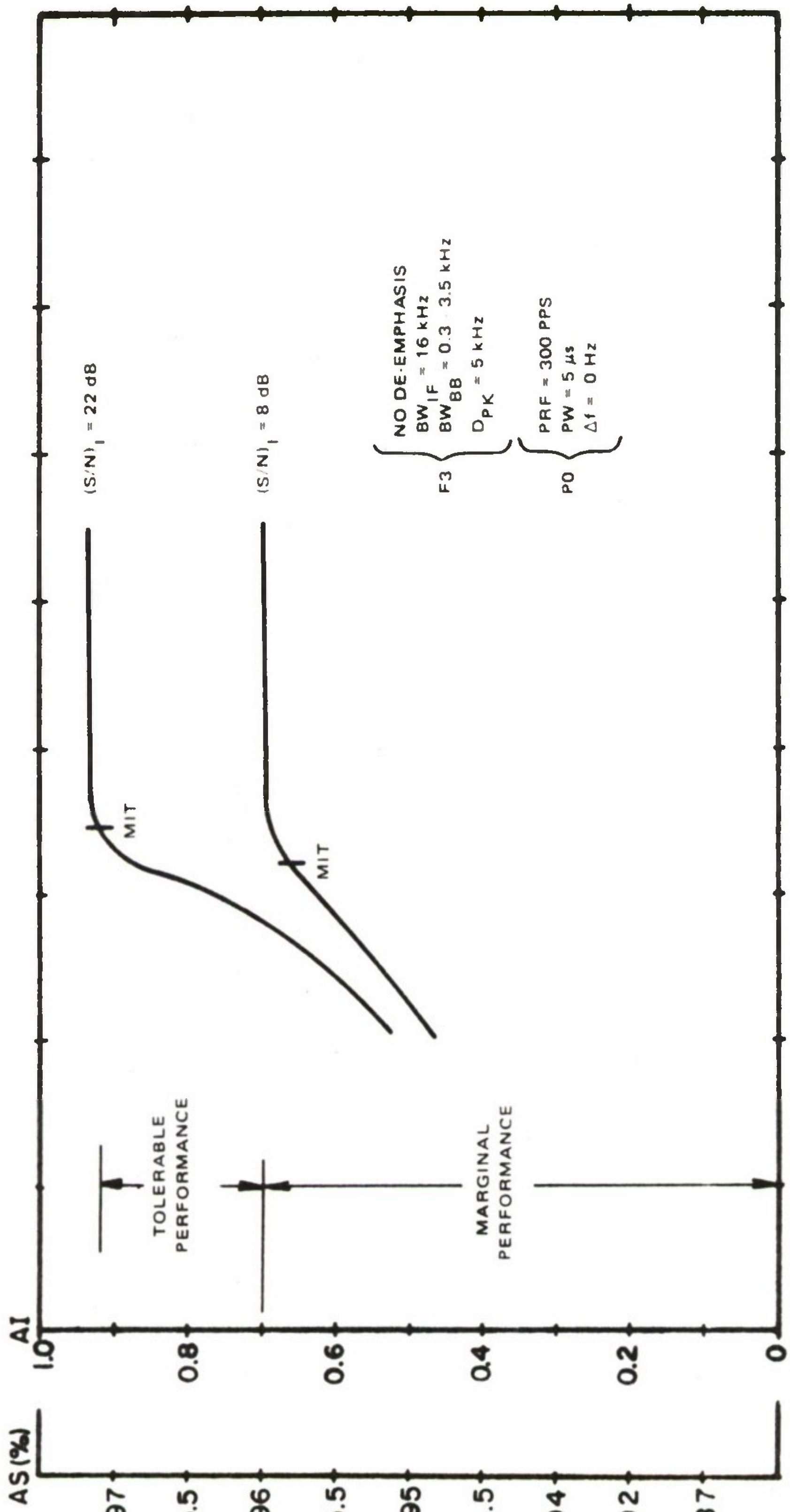


Figure III-64. Performance Degradation Curve For F3 Receiver With PO Interference

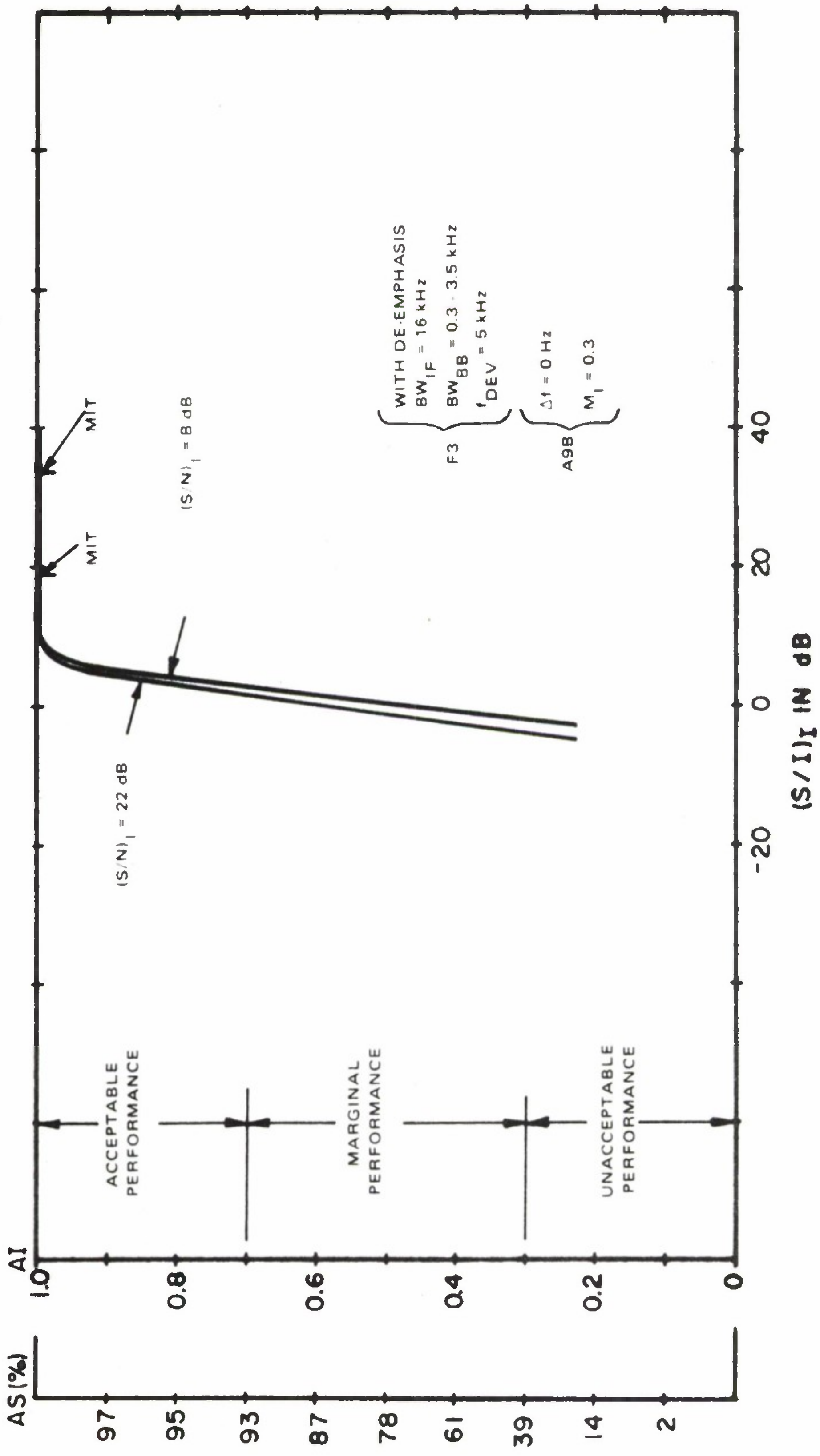


Figure III-65. Performance Degradation Curve For F3 (De-Emphasis) Receiver With A9B Interference

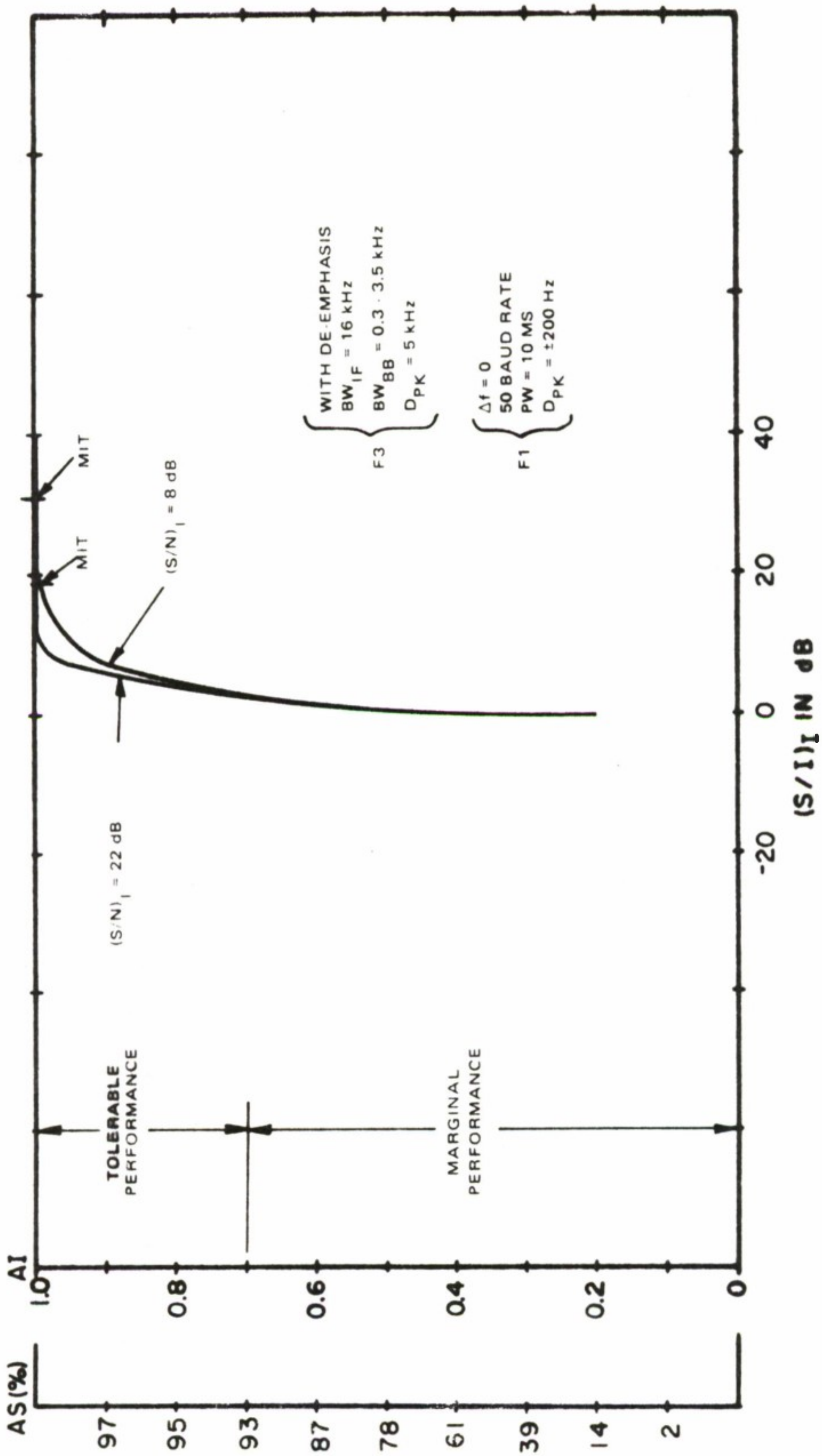


Figure III-66. Performance Degradation Curve For F3 (De-Emphasis) Receiver With F1 Interference

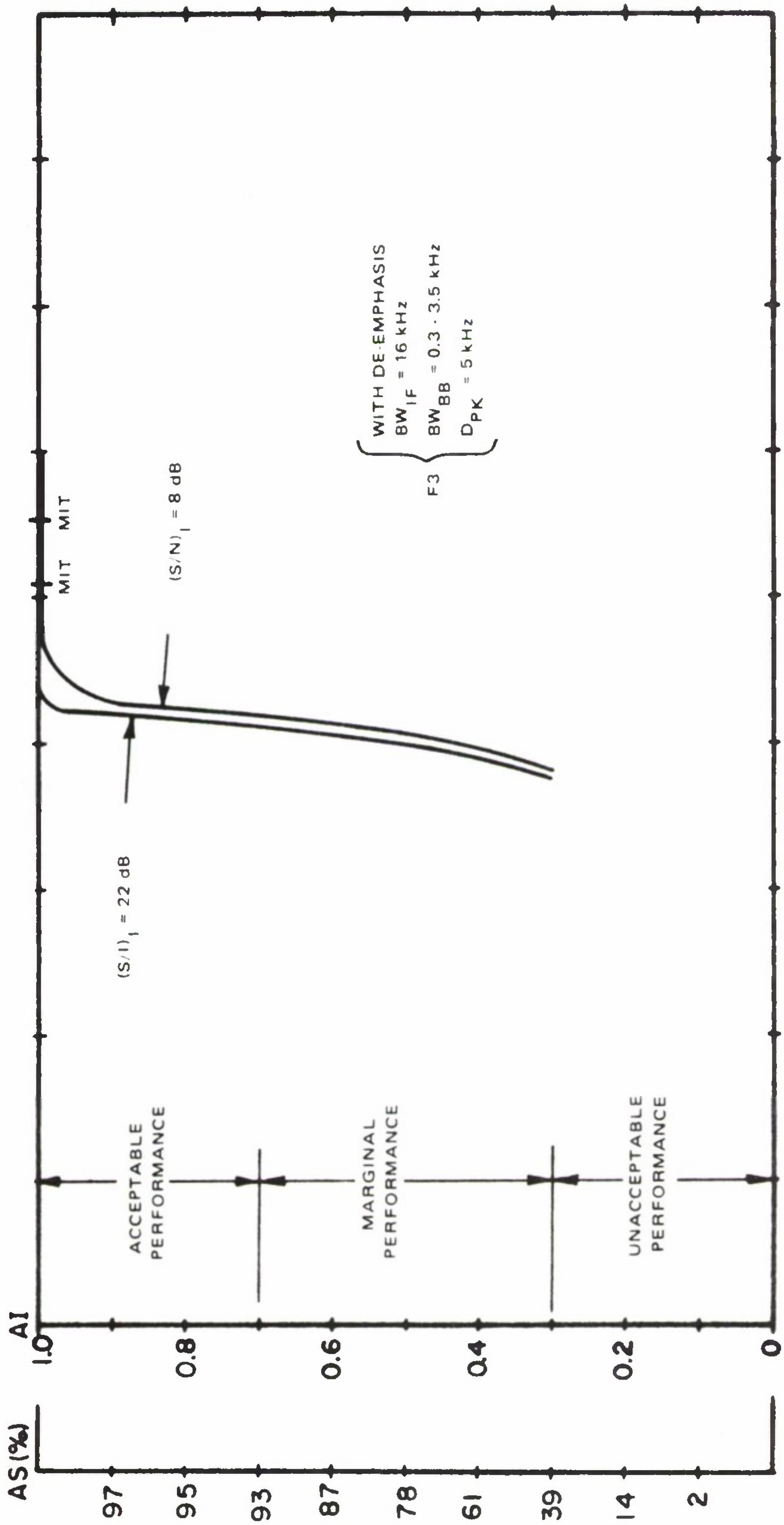


Figure III-67. Performance Degradation Curve For F3 (De-Emphasis) Receiver With F3 Interference

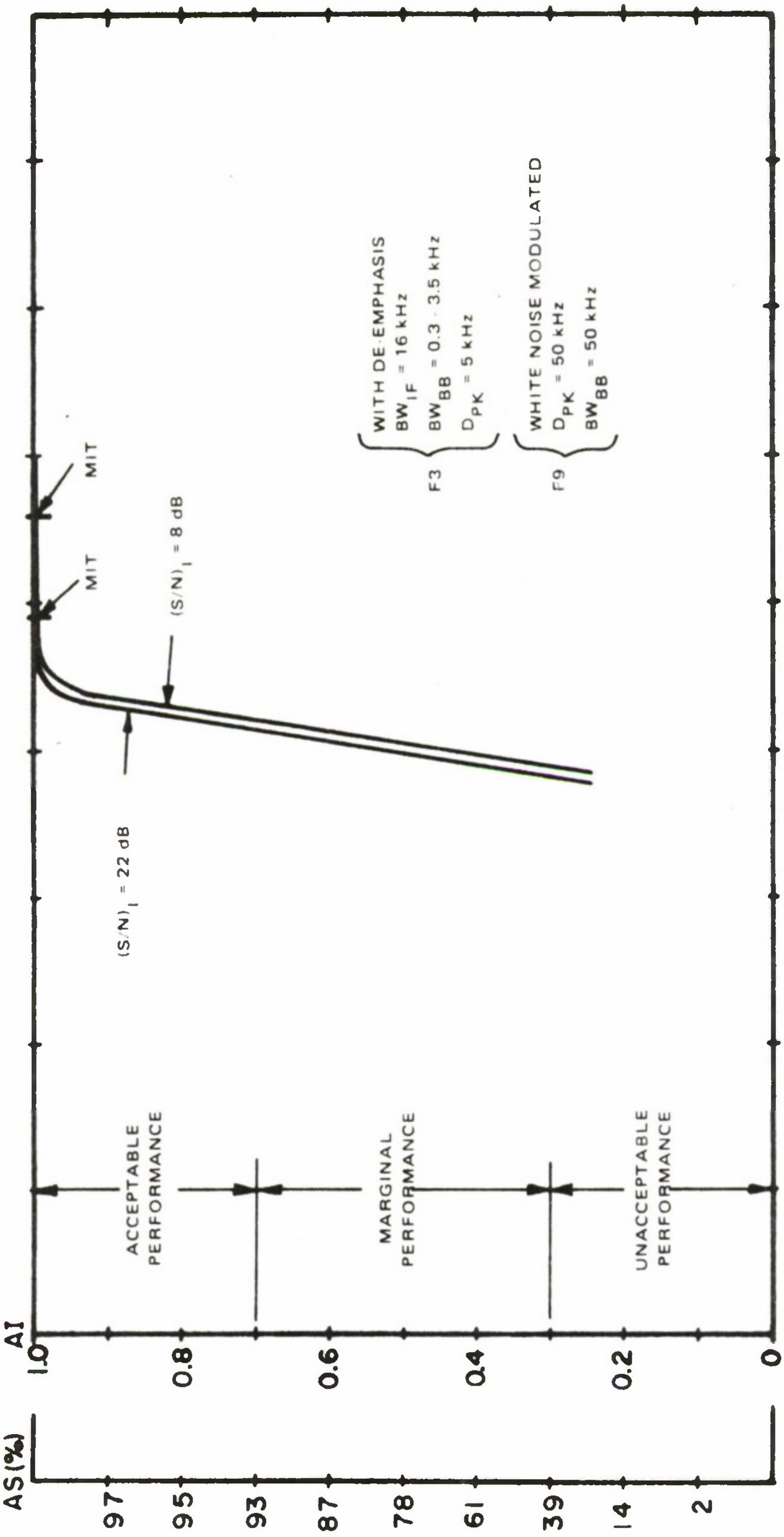


Figure III-68. Performance Degradation Curve For F3 (De-Emphasis) Receiver With F9 Interference

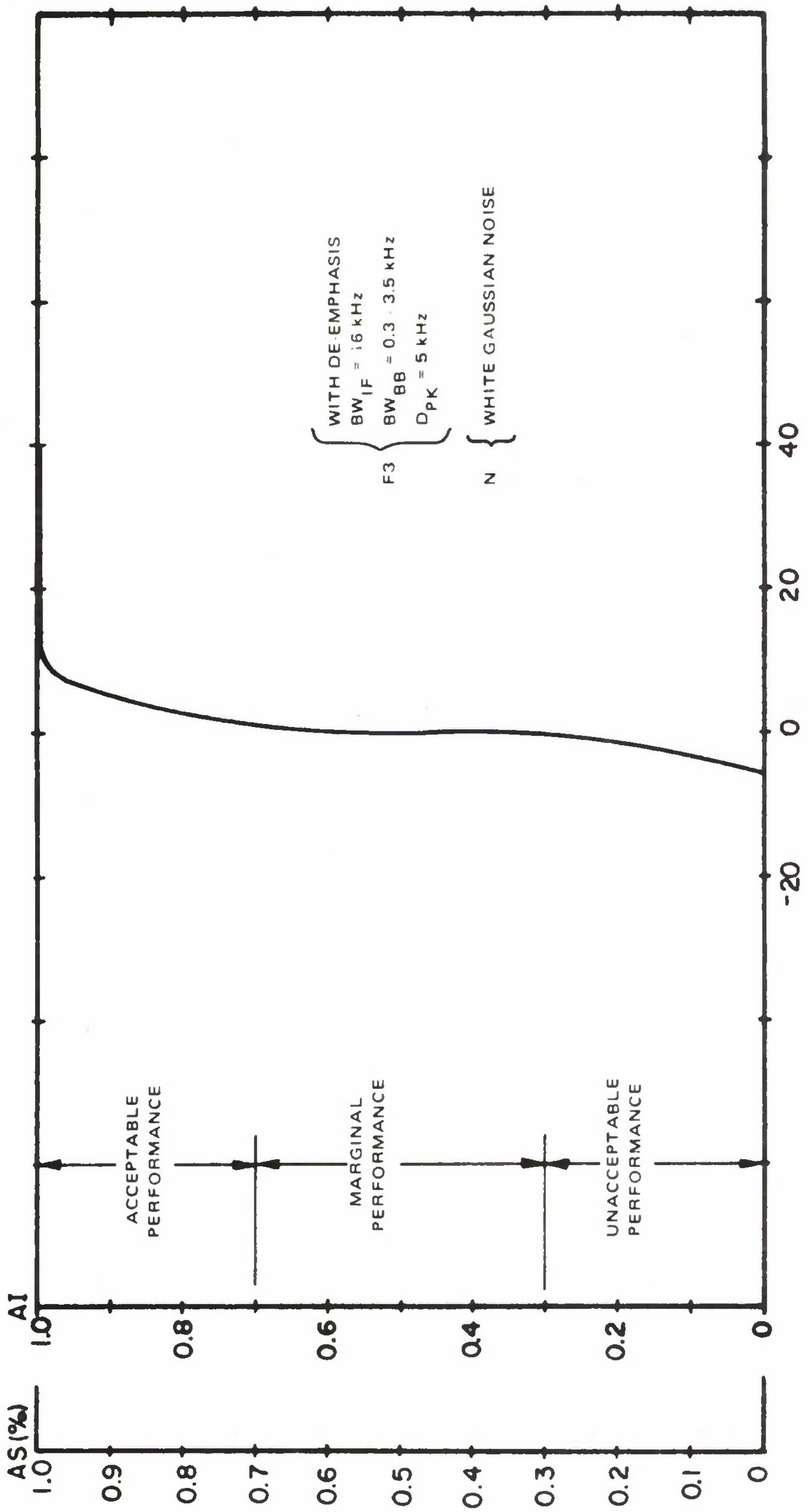


Figure III-69. Performance Degradation Curve For F3 (De-Emphasis) Receiver With Noise

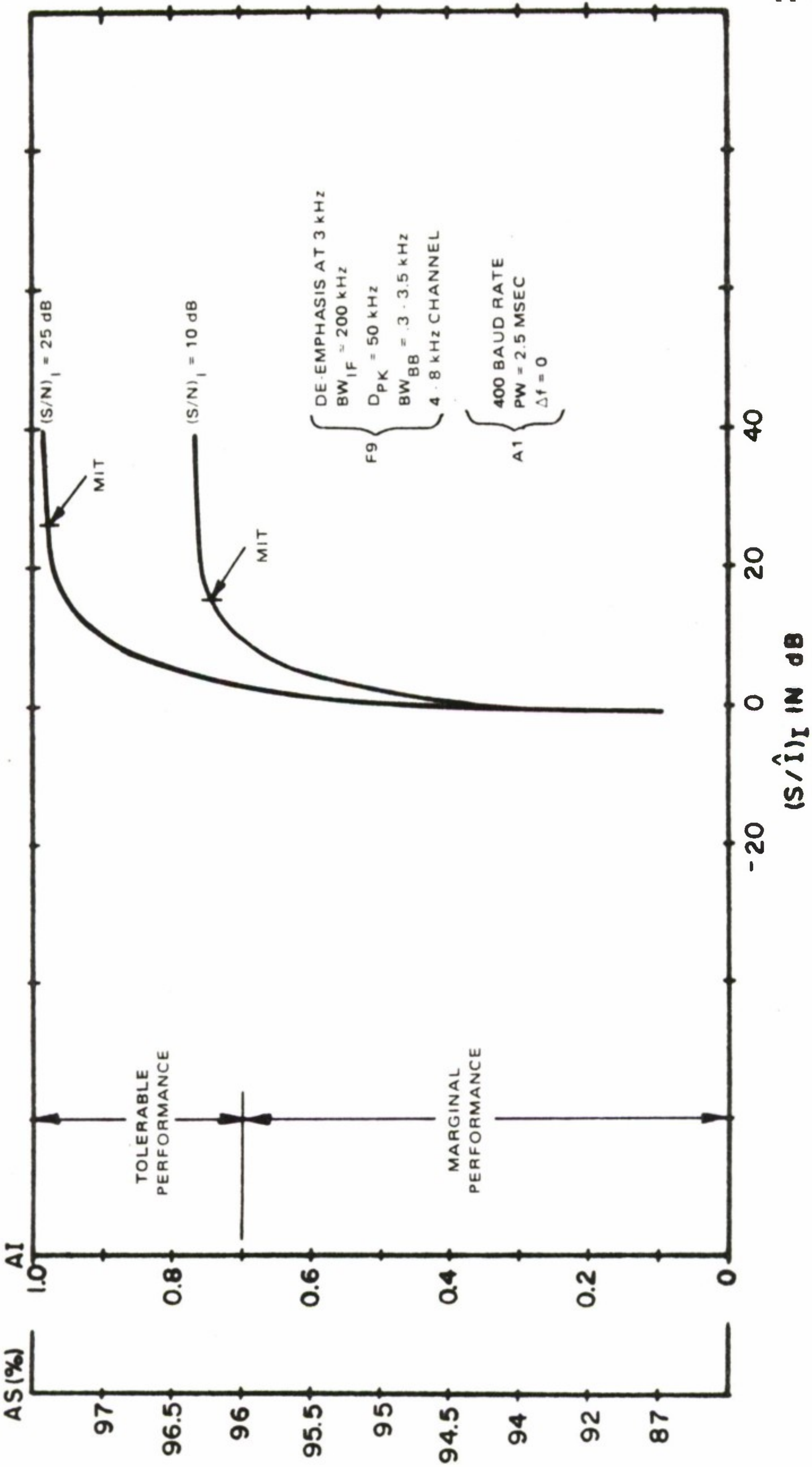


Figure III-70. Performance Degradation Curve For F9 Receiver With A1 Interference (4-8 kHz Lower Channel, 400 Baud Rate, Δf = 0 Hz)

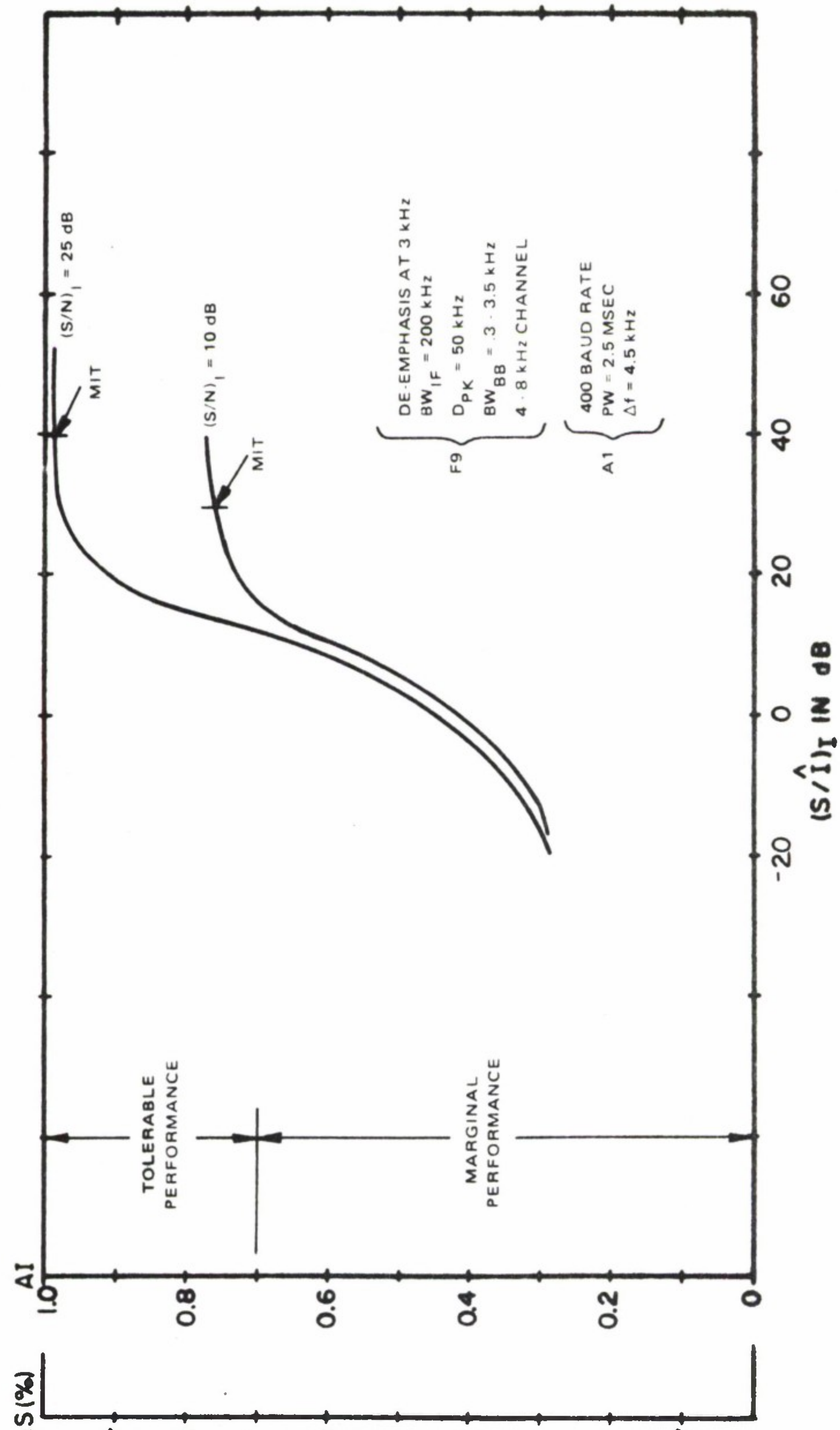


Figure III-71. Performance Degradation Curve For F9 Receiver With A1 Interference (4-8 kHz Lower Channel, 400 Baud Rate, Δf = 4.5 kHz)

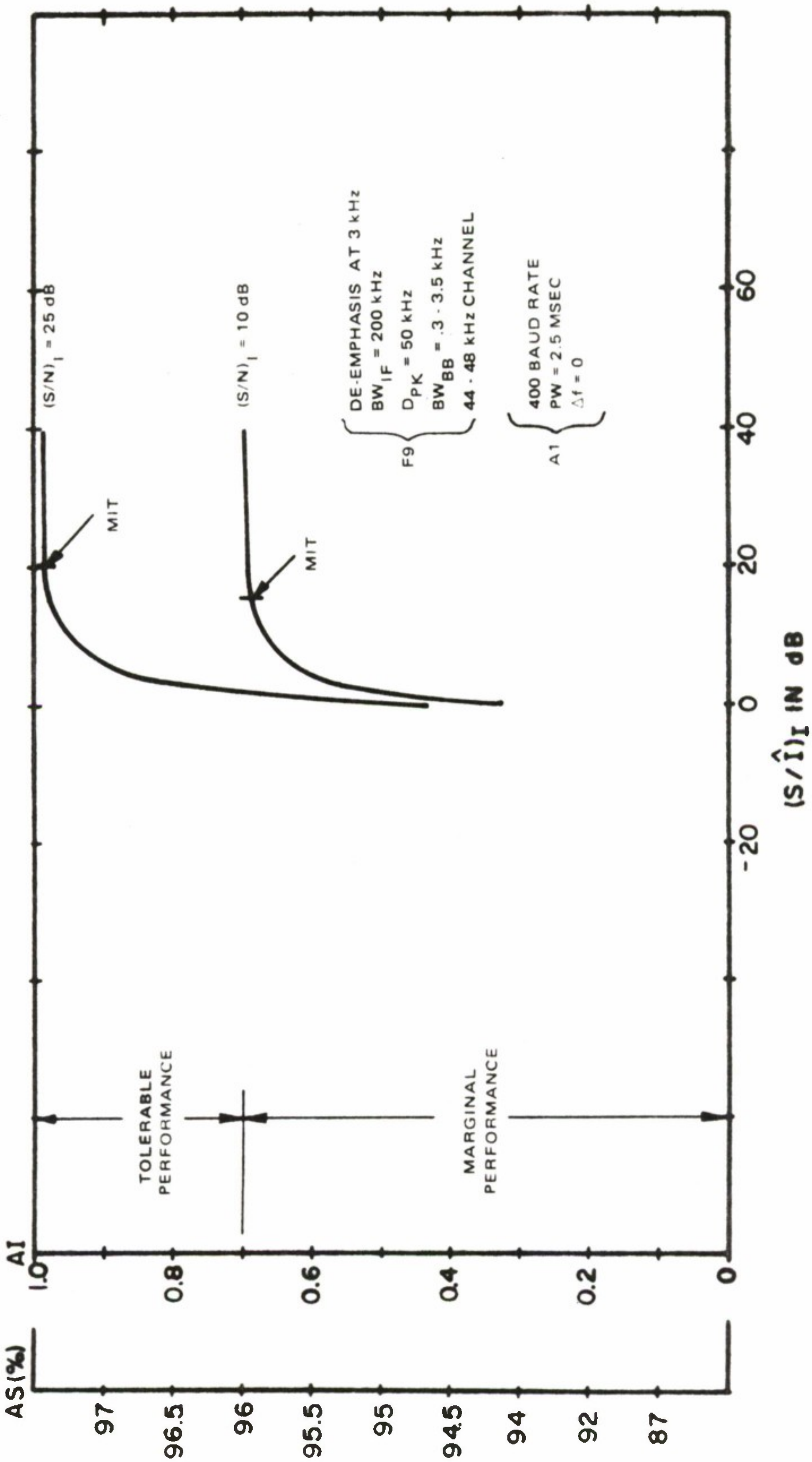


Figure III-72. Performance Degradation Curve For F9 Receiver With A1 Interference (44-48 kHz Upper Channel, 400 Baud Rate, $\Delta f = 0$ Hz)

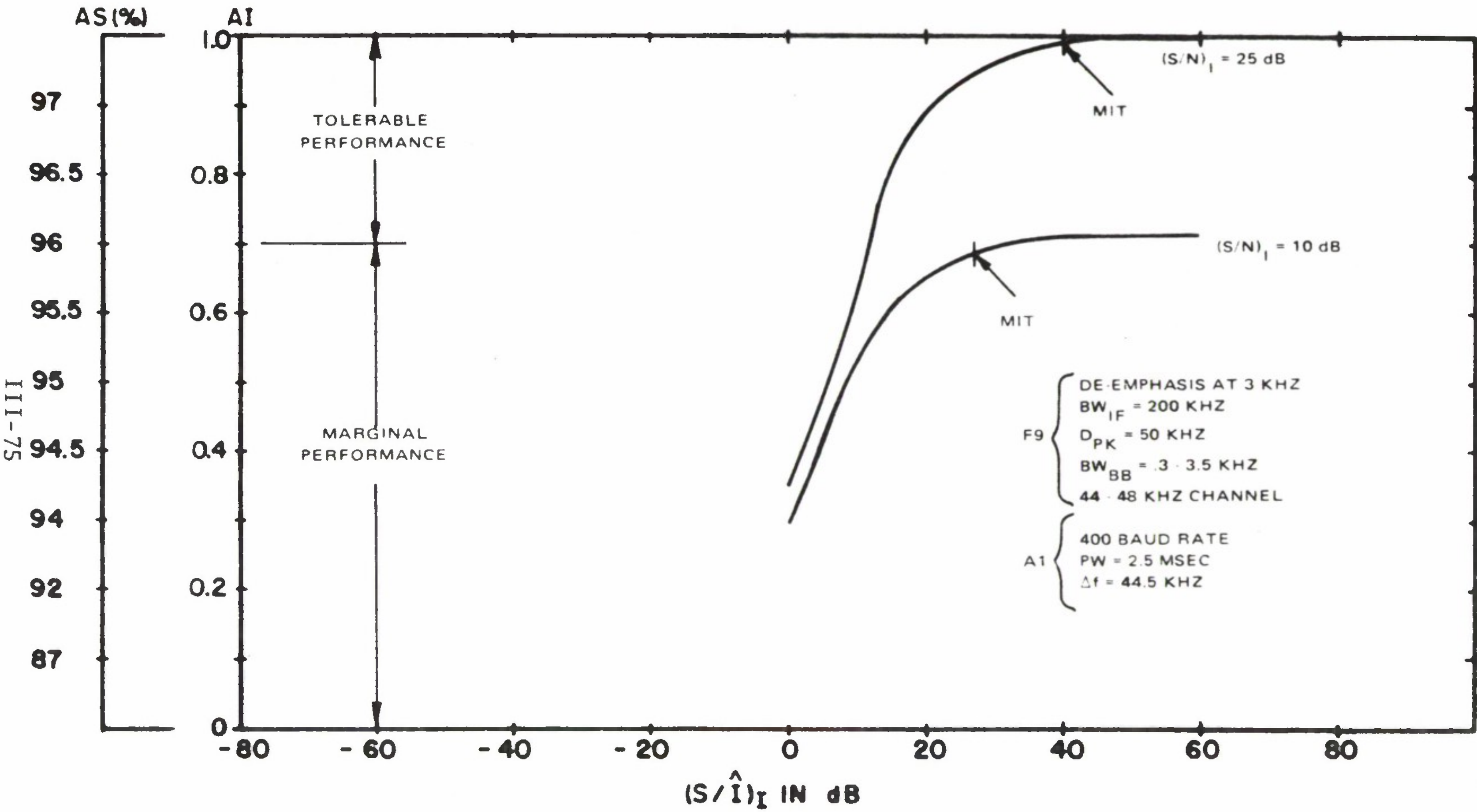


Figure III-73. Performance Degradation Curve For F9 Receiver With A1 Interference (44-48 kHz Upper Channel 400 Baud Rate, Δf = 44.5 kHz)

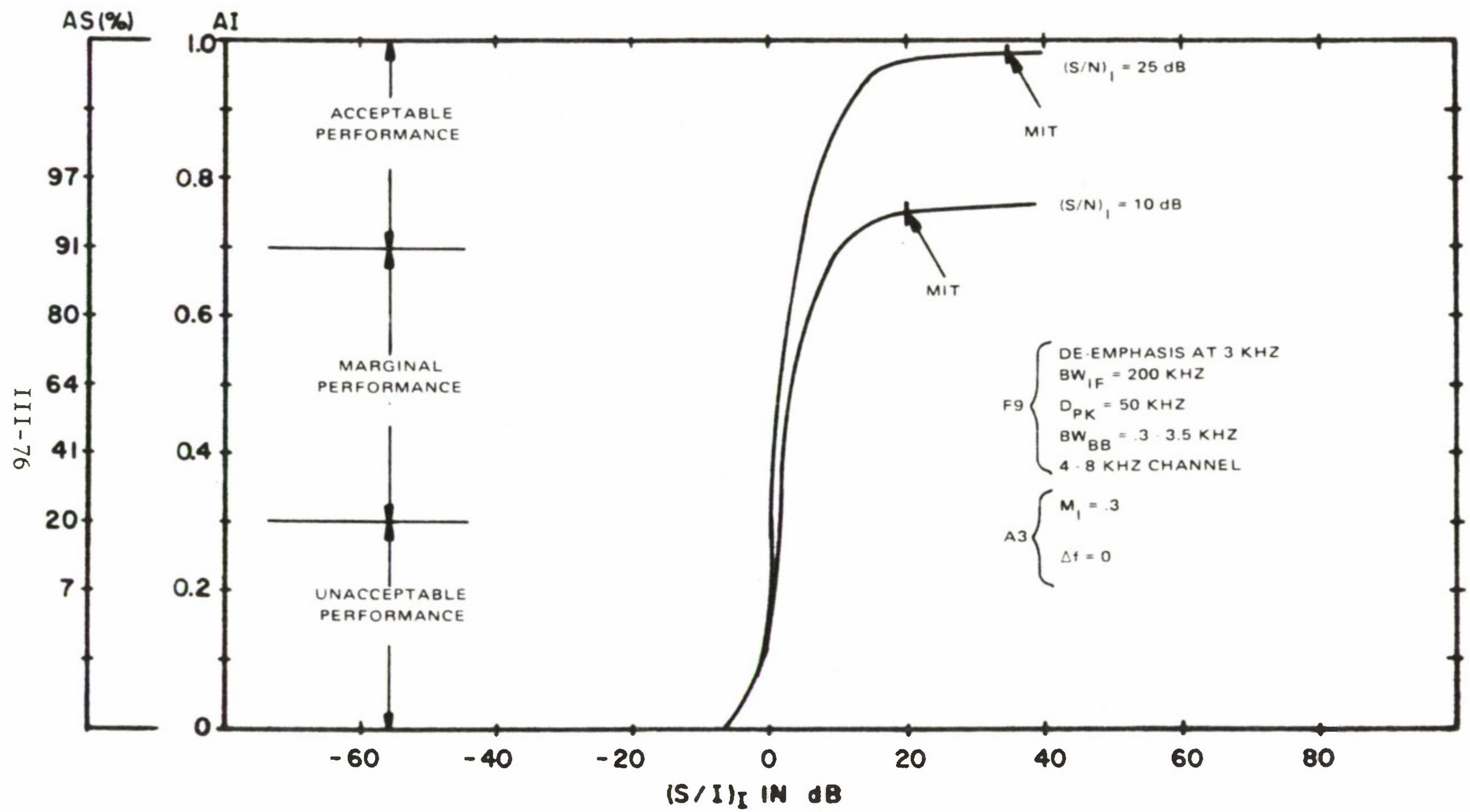


Figure III-74. Performance Degradation Curve For F9 Receiver With A3 Interference (4-8 kHz Lower Channel, $\Delta f = 0$ Hz)

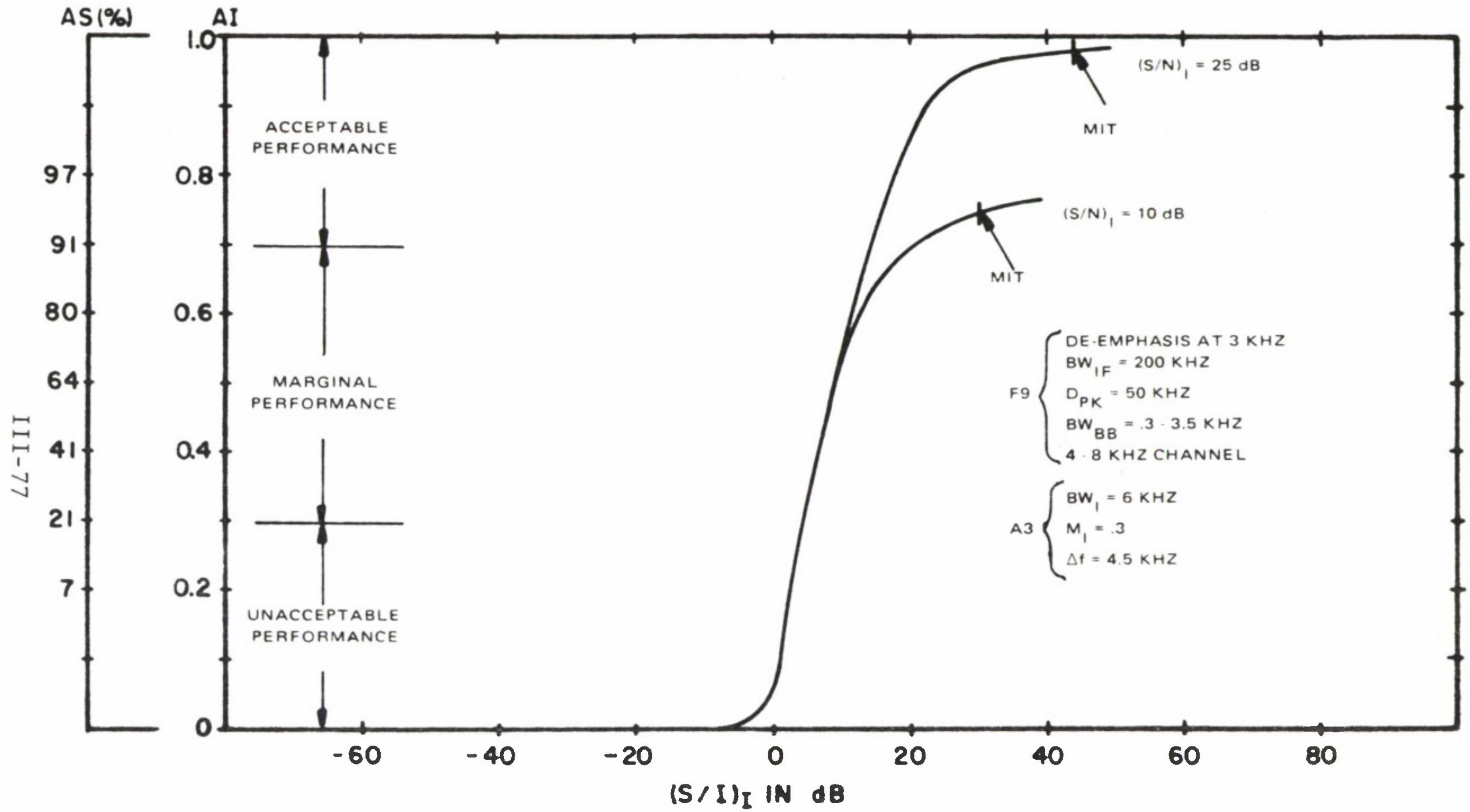


Figure III-75. Performance Degradation Curve For F9 Receiver With A3 Interference (4-8 kHz Lower Channel, Δf = 4.5 kHz)

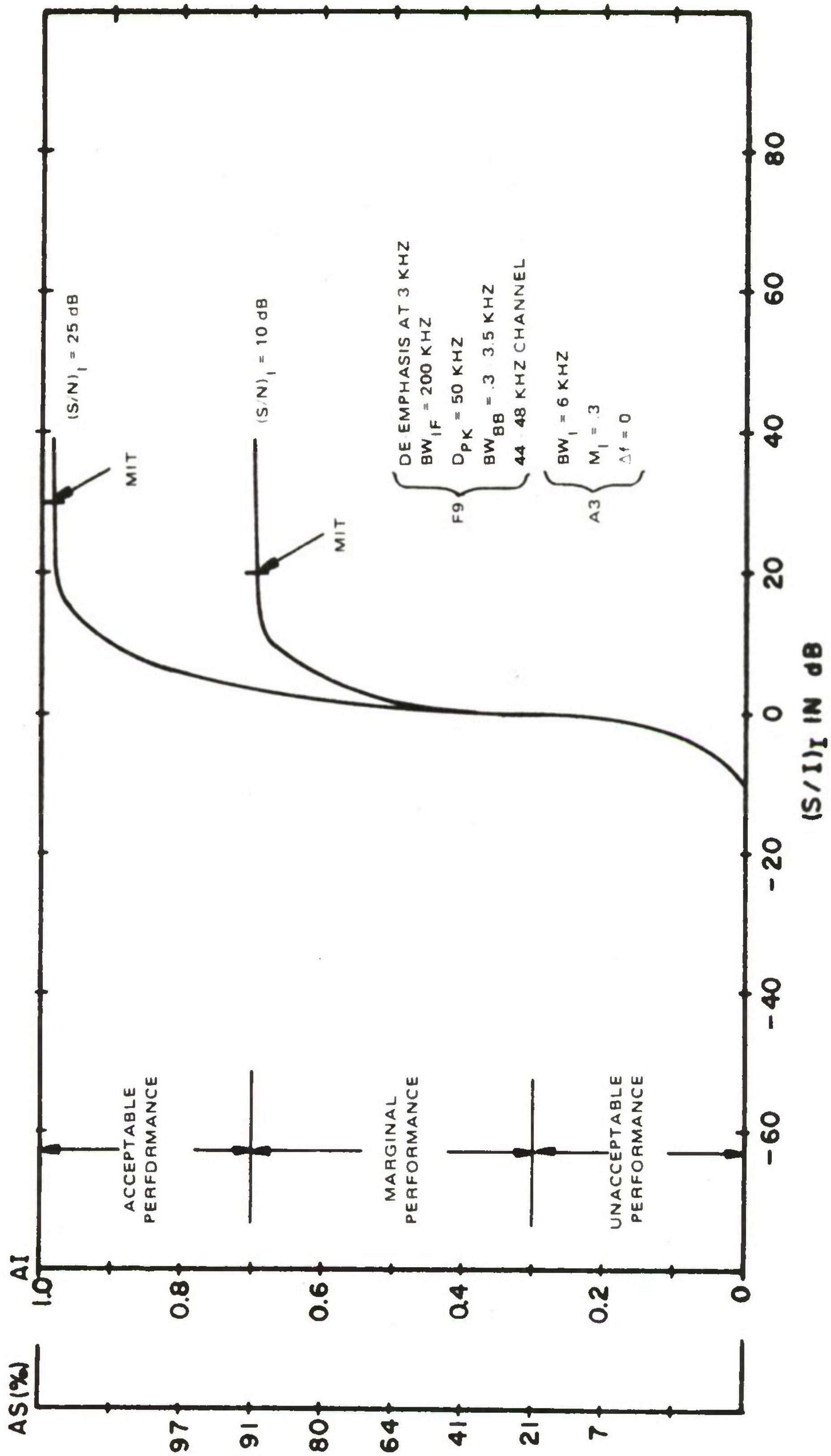


Figure III-76. Performance Degradation Curve For F9 Receiver With A3 Interference (44-48 kHz Upper Channel, $\Delta f = 0$ Hz)

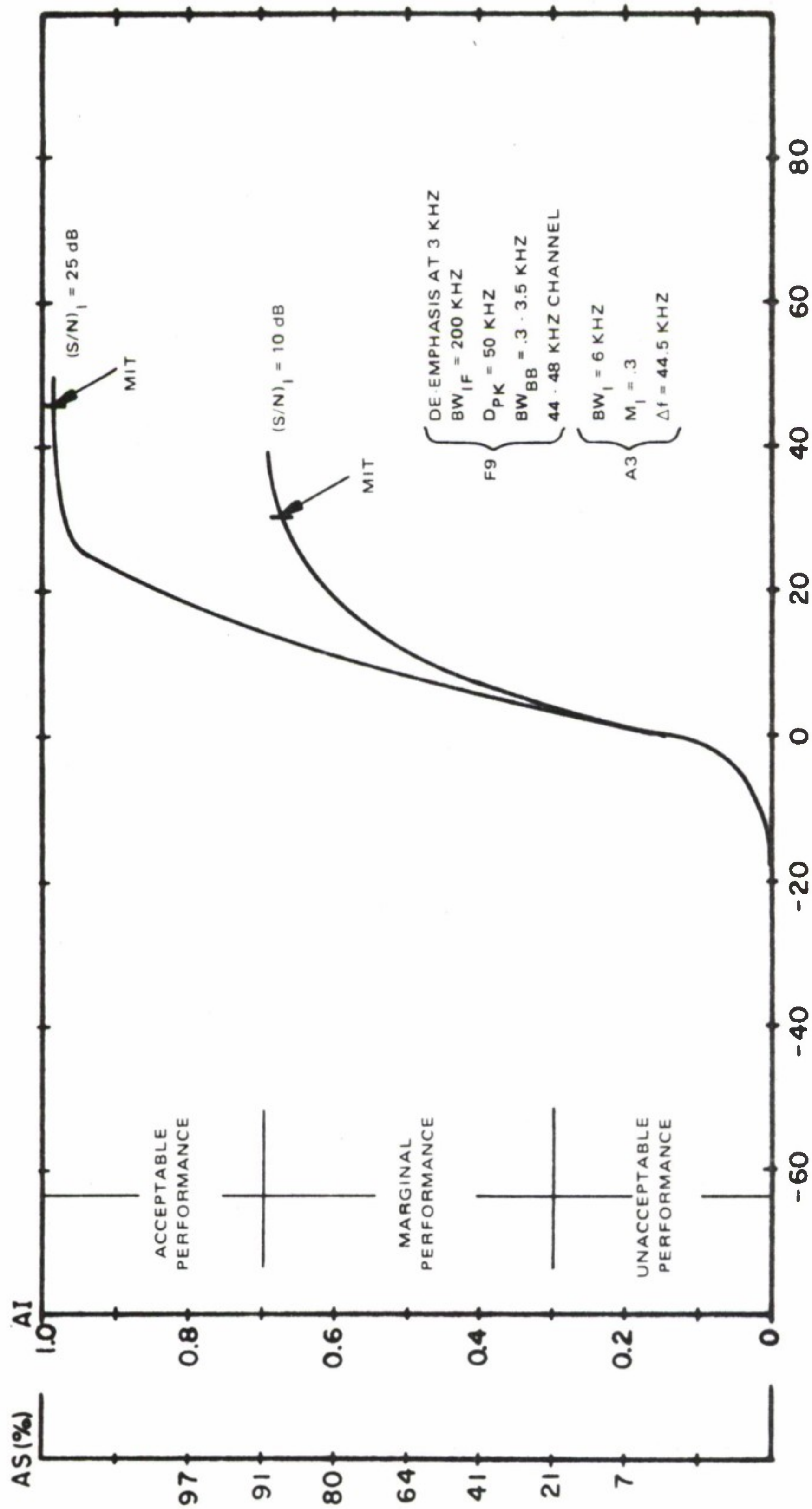


Figure III-77. Performance Degradation Curve For F9 Receiver With A3 Interference (44-48 kHz Upper Channel, Δf = 44.5 kHz)

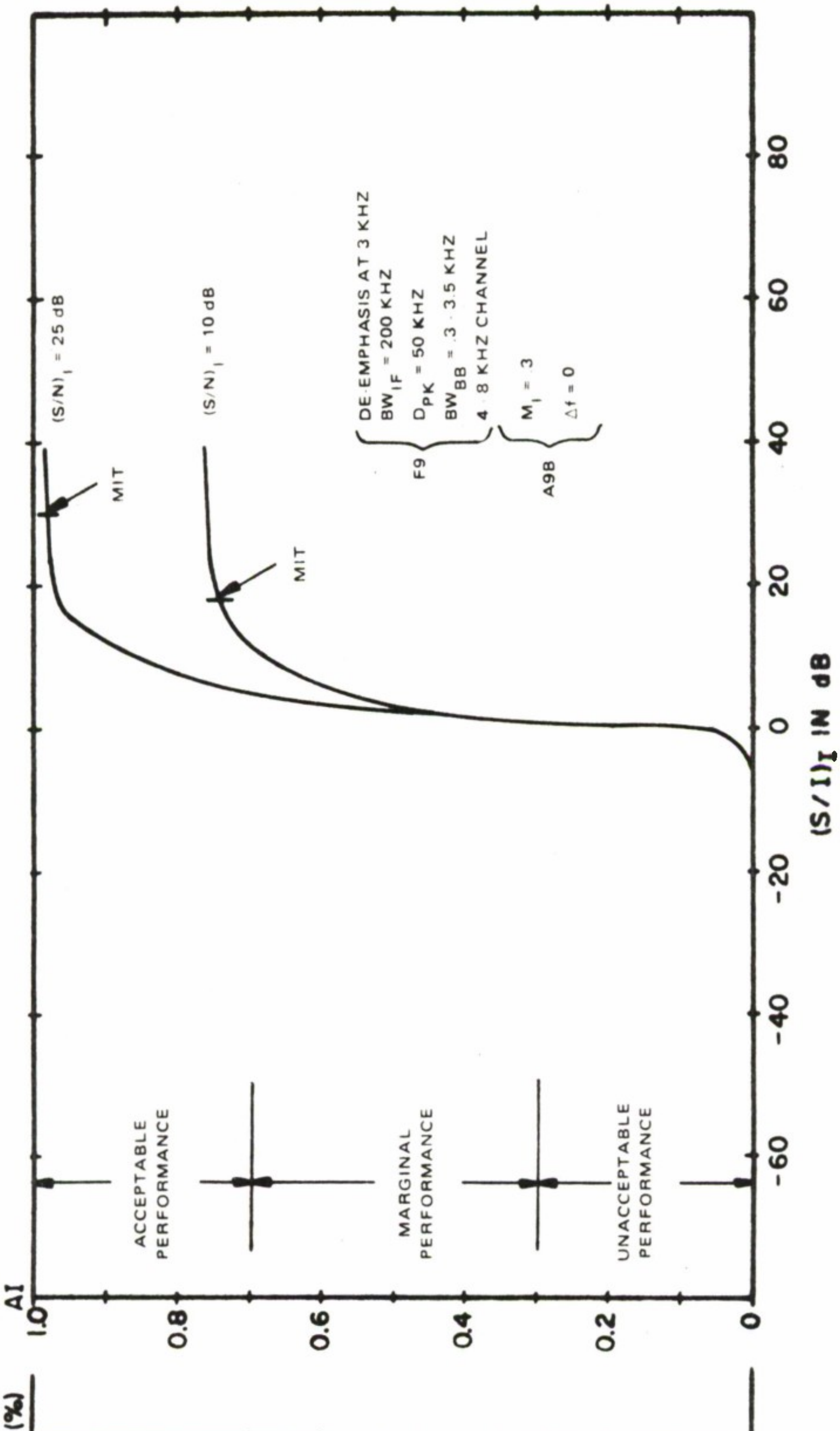


Figure III-78. Performance Degradation Curve For F9 Receiver With A9B Interference (4-8 kHz Lower Channel, Δf = 0 Hz)

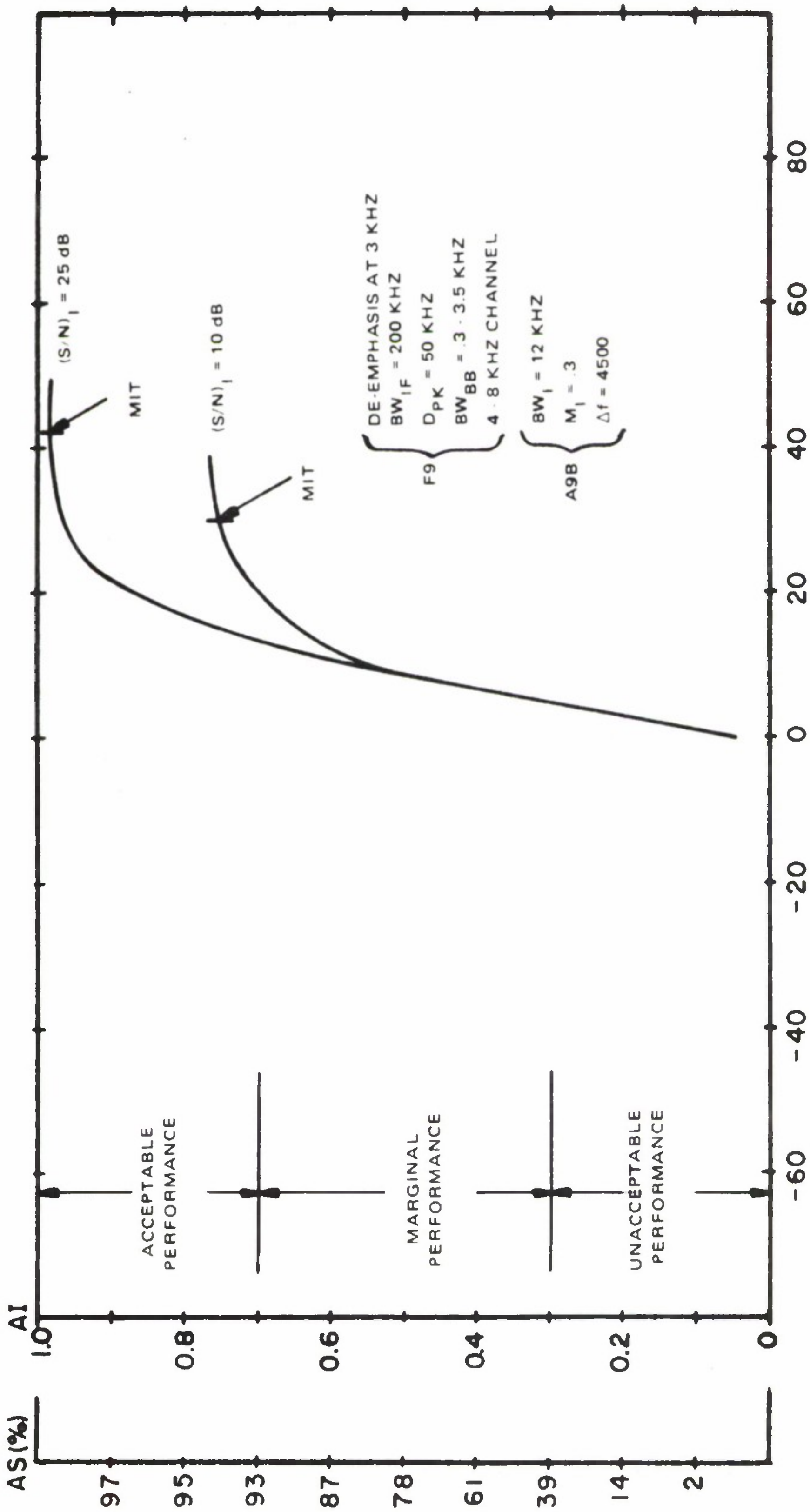


Figure III-79. Performance Degradation Curve For F9 Receiver With A9B Interference (4-8 kHz Lower Channel, Δf = 4.5 kHz)

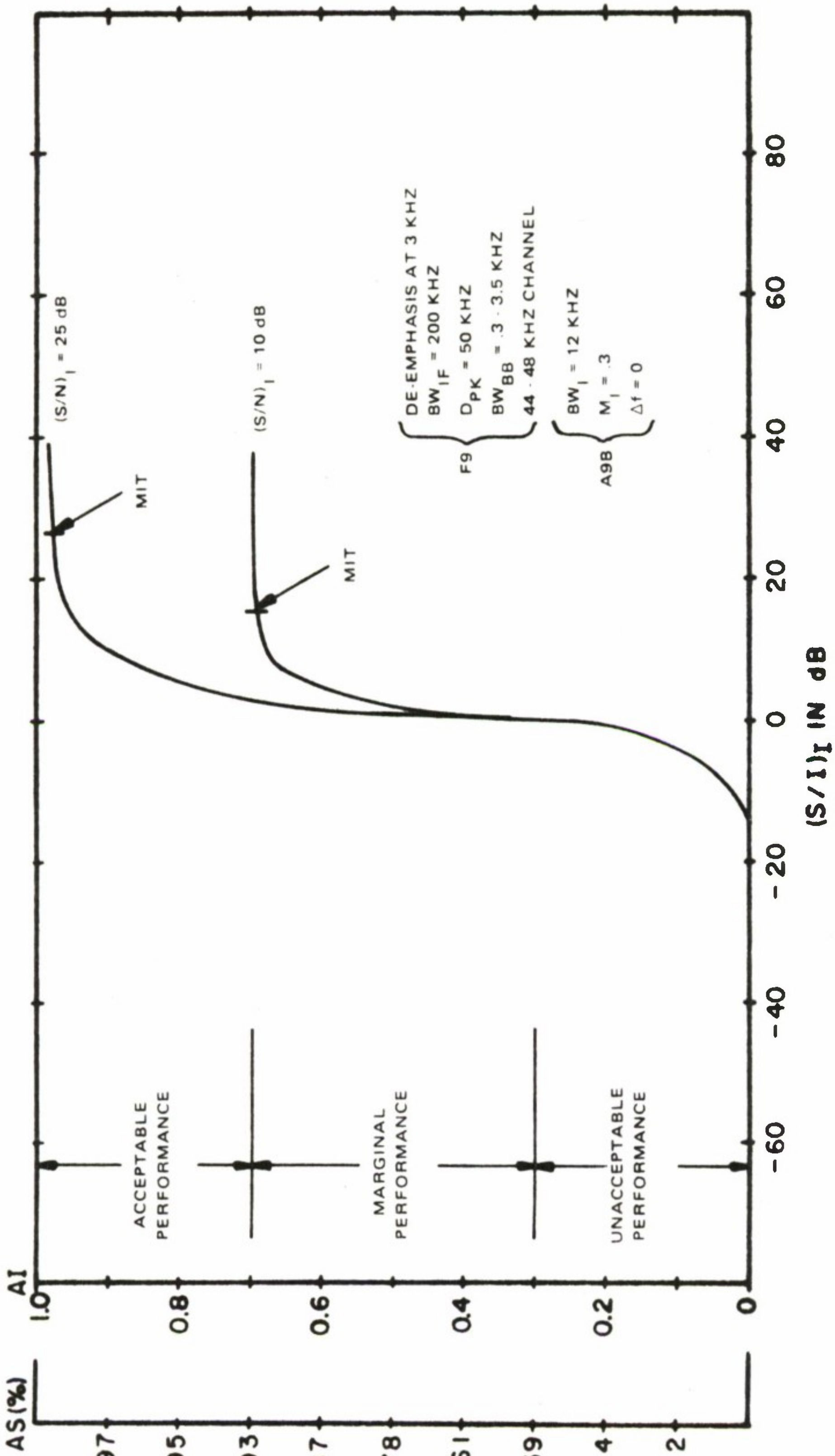


Figure III-80. Performance Degradation Curve For F9 Receiver With A9B Interference (44-48 kHz Upper Channel Δf = 0 Hz)

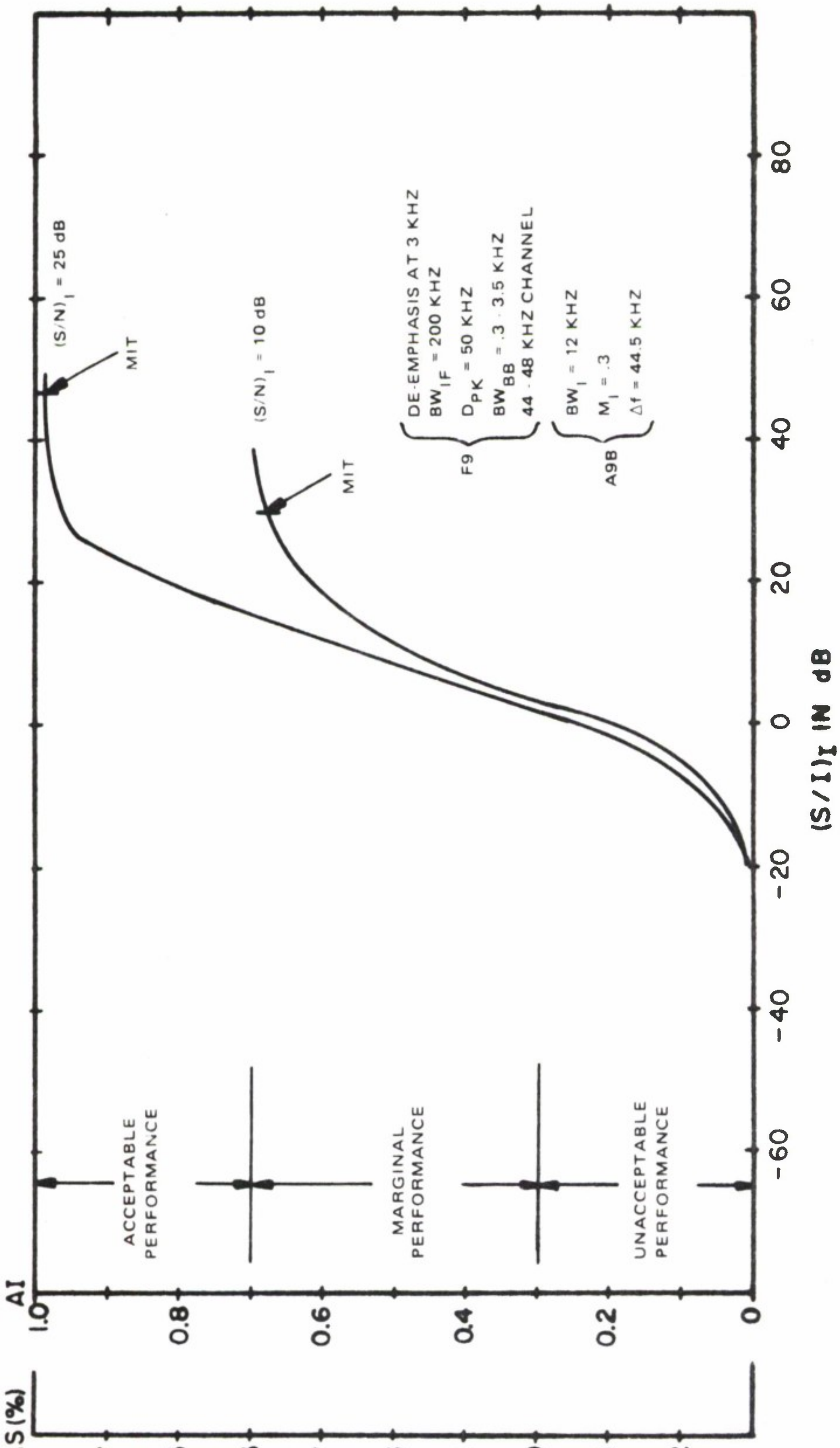


Figure III-81. Performance Degradation Curve For F9 Receiver With A9B Interference (44-48 kHz Upper Channel, Δf = 44.5 kHz)

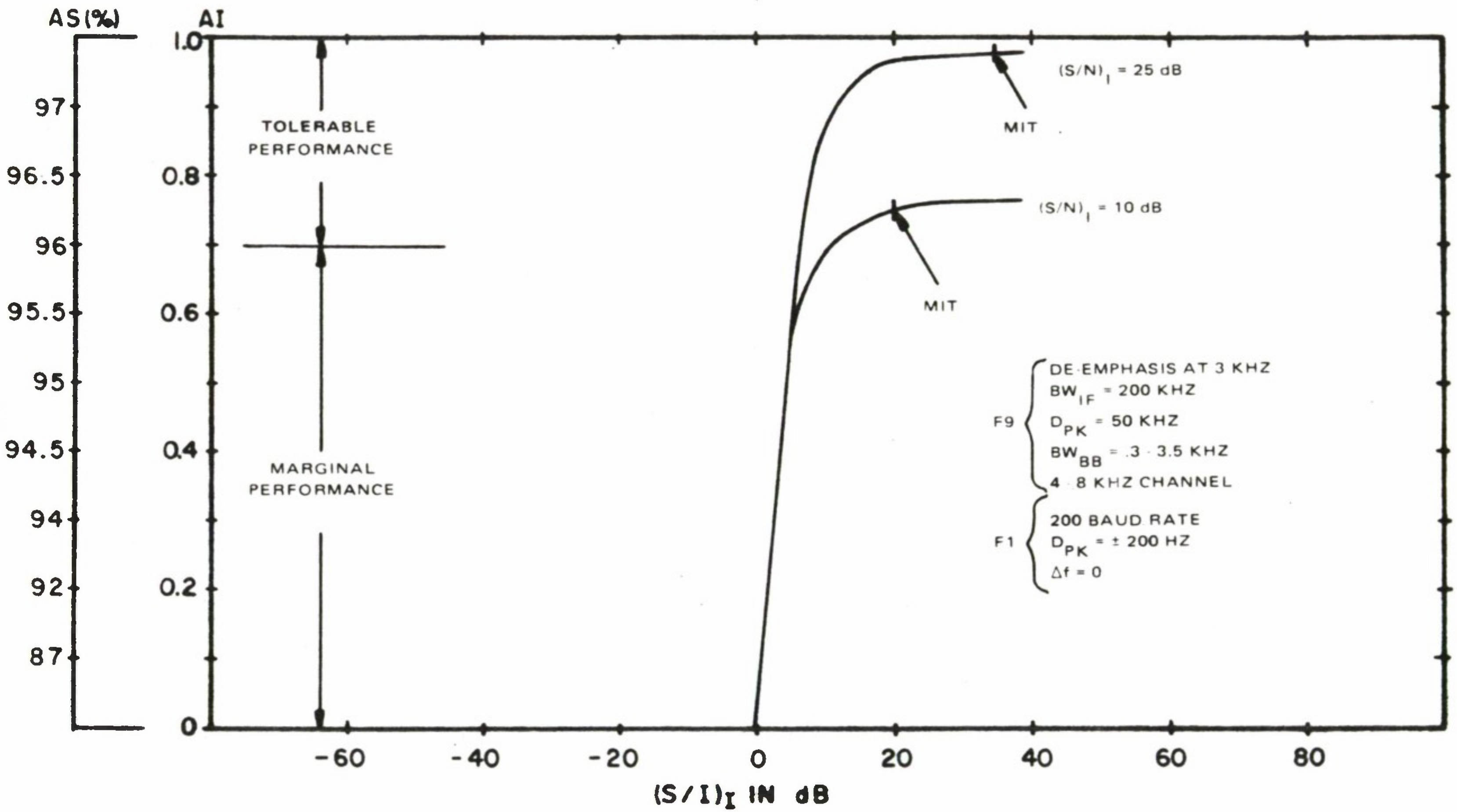


Figure III-82. Performance Degradation Curve For F9 Receiver With F1 Interference (4-8 kHz Lower Channel, Δf = 0 Hz)

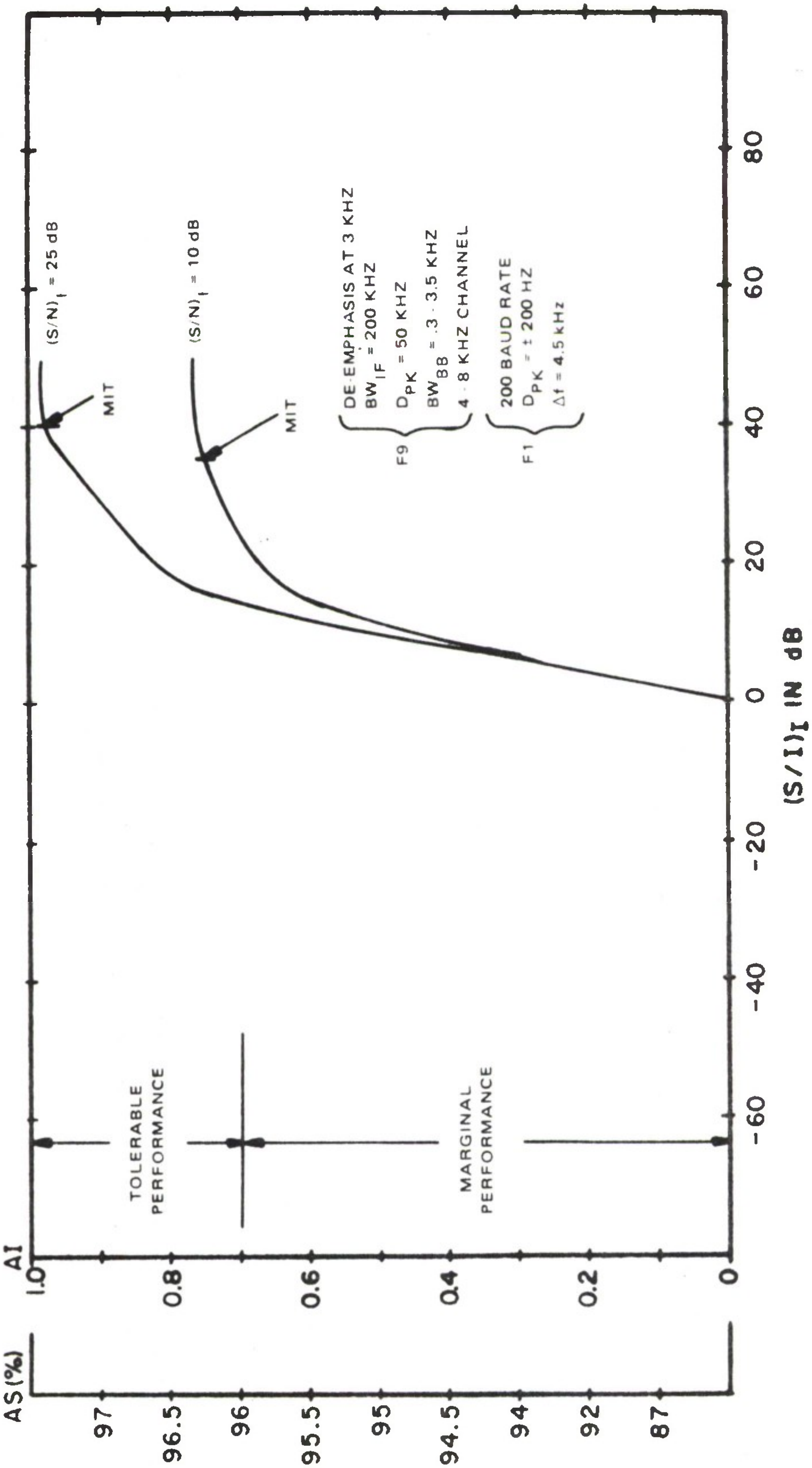


Figure III-83. Performance Degradation Curve For F9 Receiver With F1 Interference 4-8 kHz Lower Channel, $\Delta f = 4.5$ kHz)

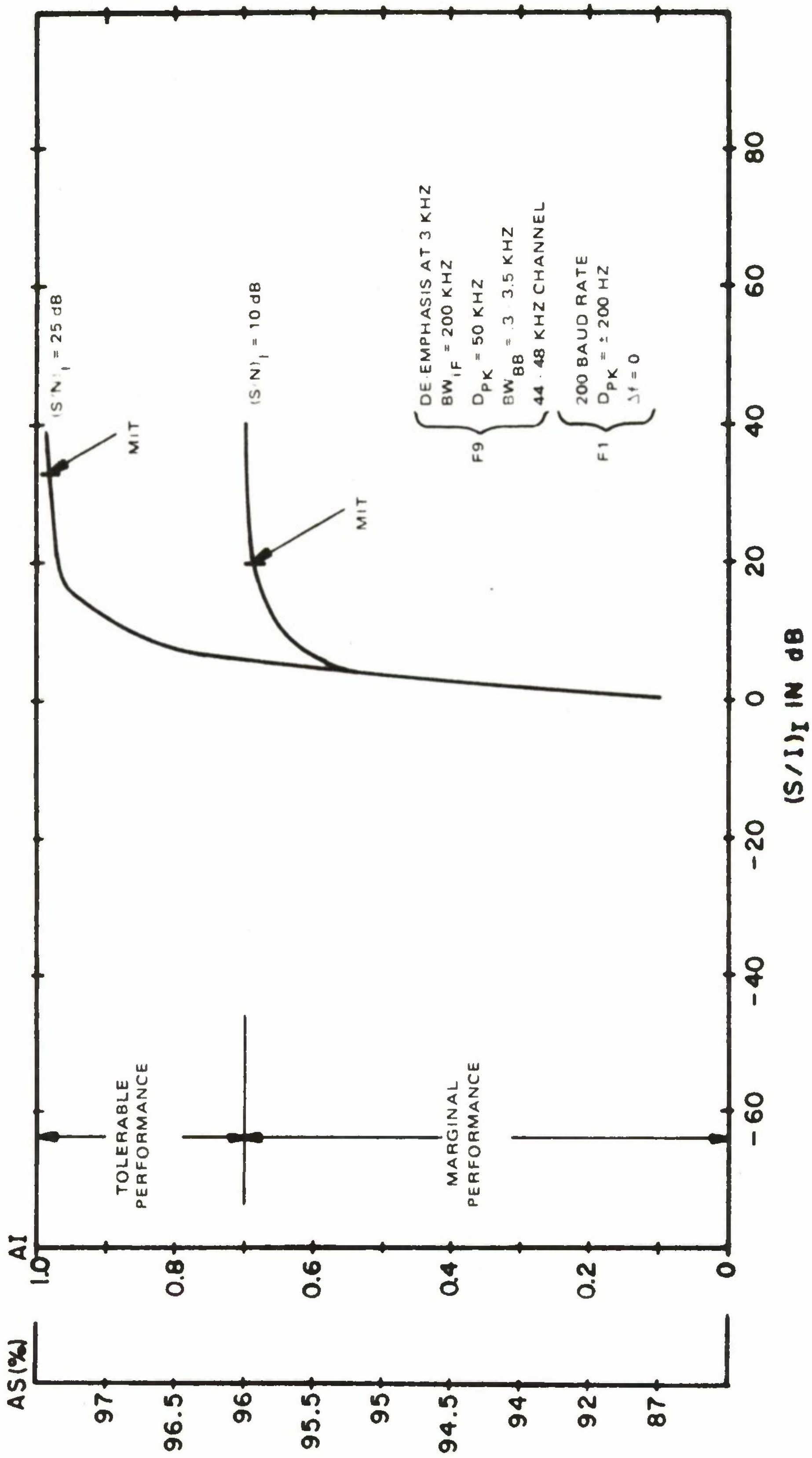


Figure III-84. Performance Degradation Curve For F9 Receiver With F1 Interference (44-48 kHz Upper Channel, $\Delta f = 0$ Hz)

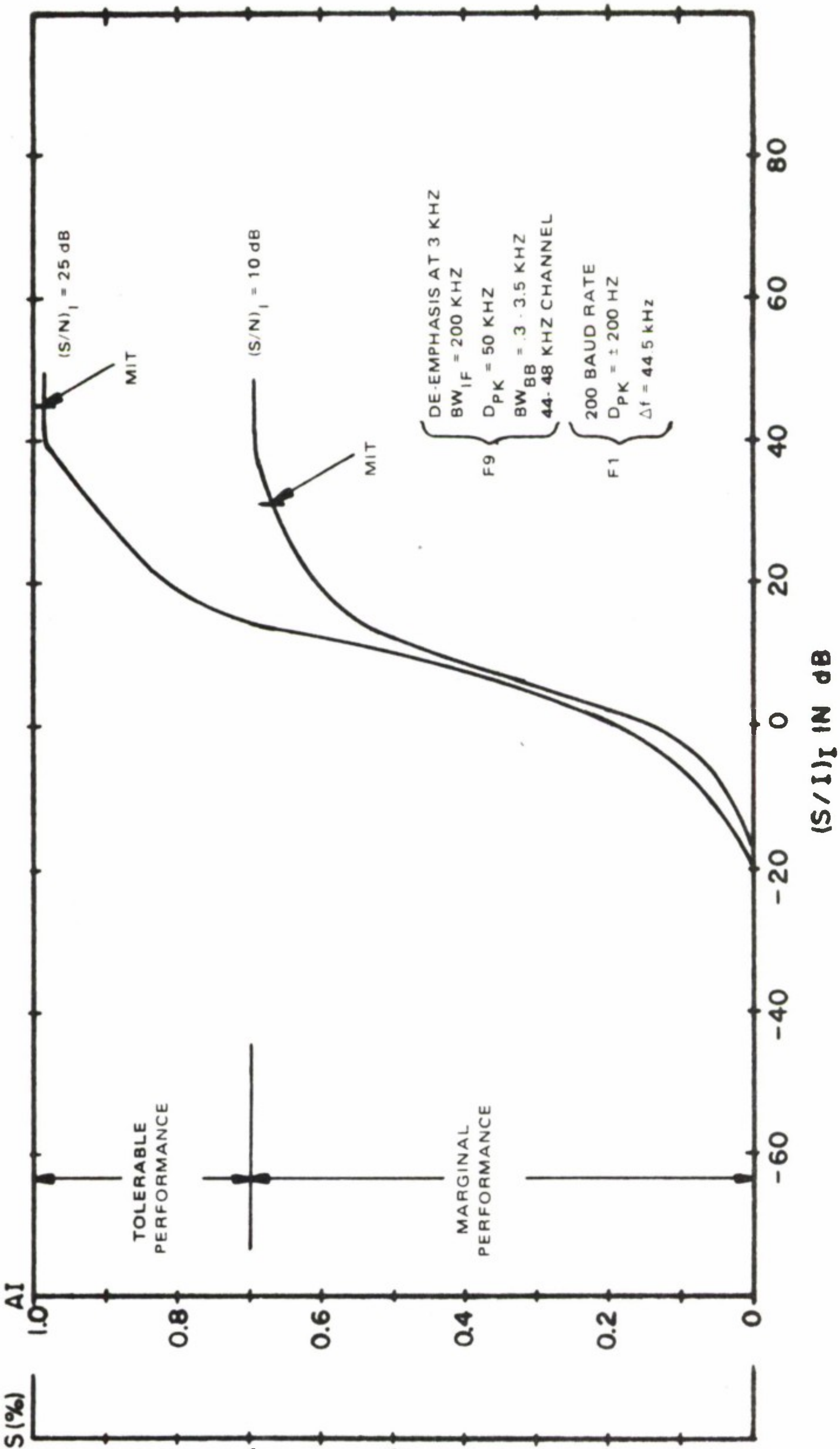


Figure III-85. Performance Degradation Curve For F9 Receiver With F1 Interference (44-48 kHz Upper Channel, Δf = 44.5 kHz)

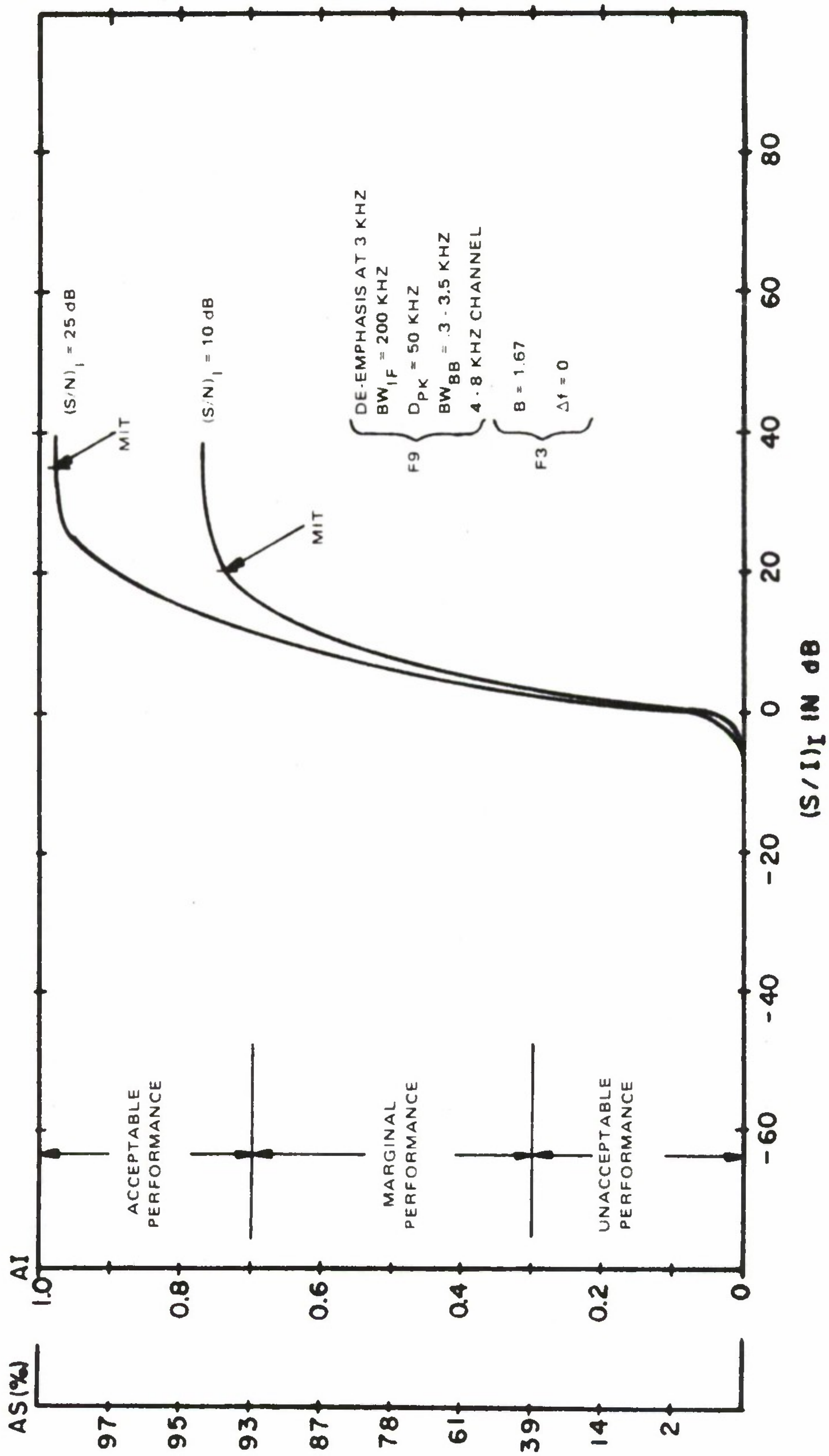


Figure III-86. Performance Degradation Curve For F9 Receiver With F3 Interference (44-48 kHz Upper Channel, Δf = 0 kHz)

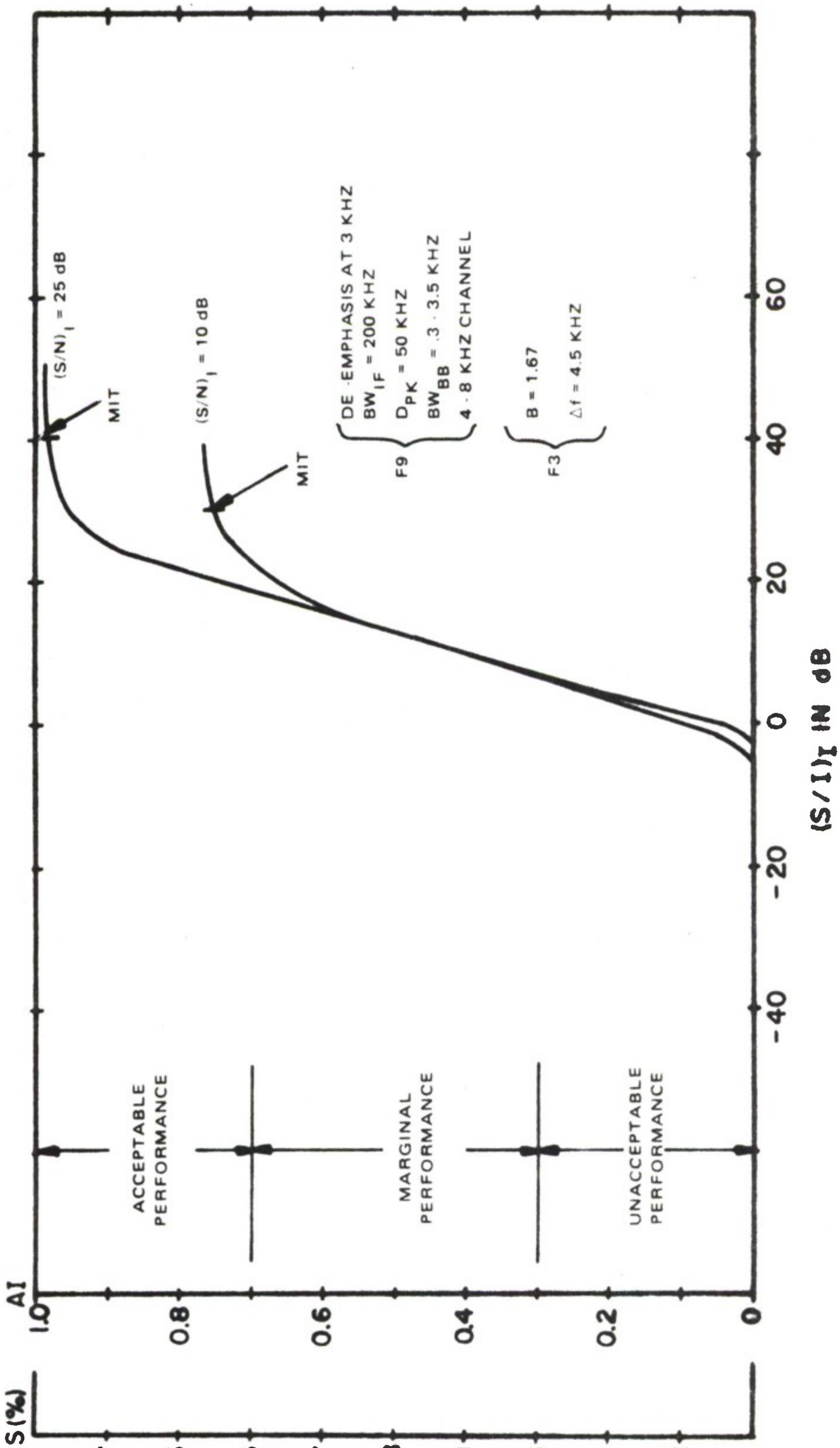


Figure III-87. Performance Degradation Curve For F9 Receiver With F3 Interference (4-8 kHz Lower Channel, Δf = 4.5 kHz)

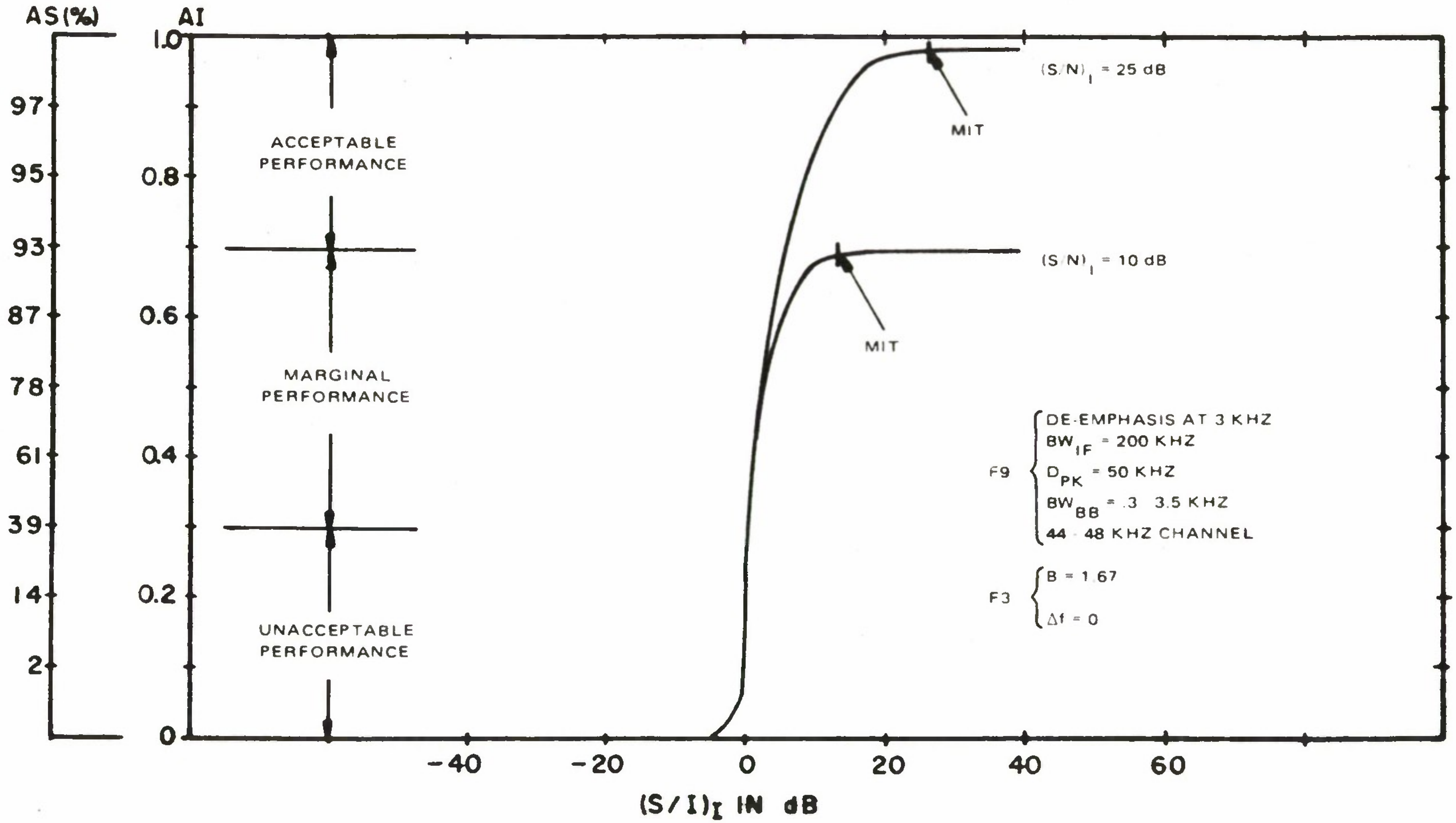


Figure III-88. Performance Degradation Curve For F9 Receiver With F3 Interference (44-48 kHz Upper Channel, Δf = 0 Hz)

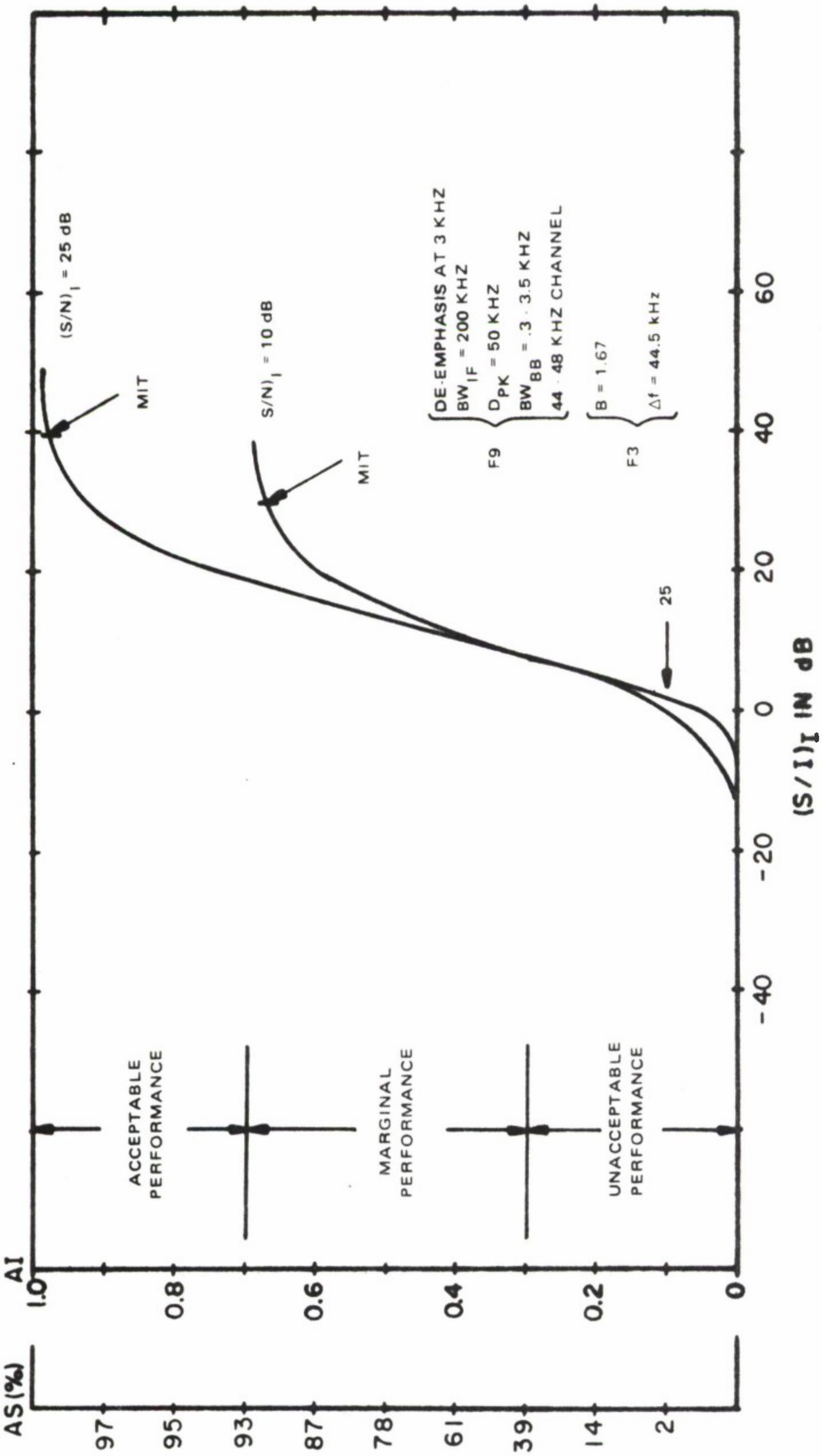


Figure III-89. Performance Degradation Curve For F9 Receiver With F3 Interference (44-48 kHz Upper Channel, Δf = 44.5 kHz)

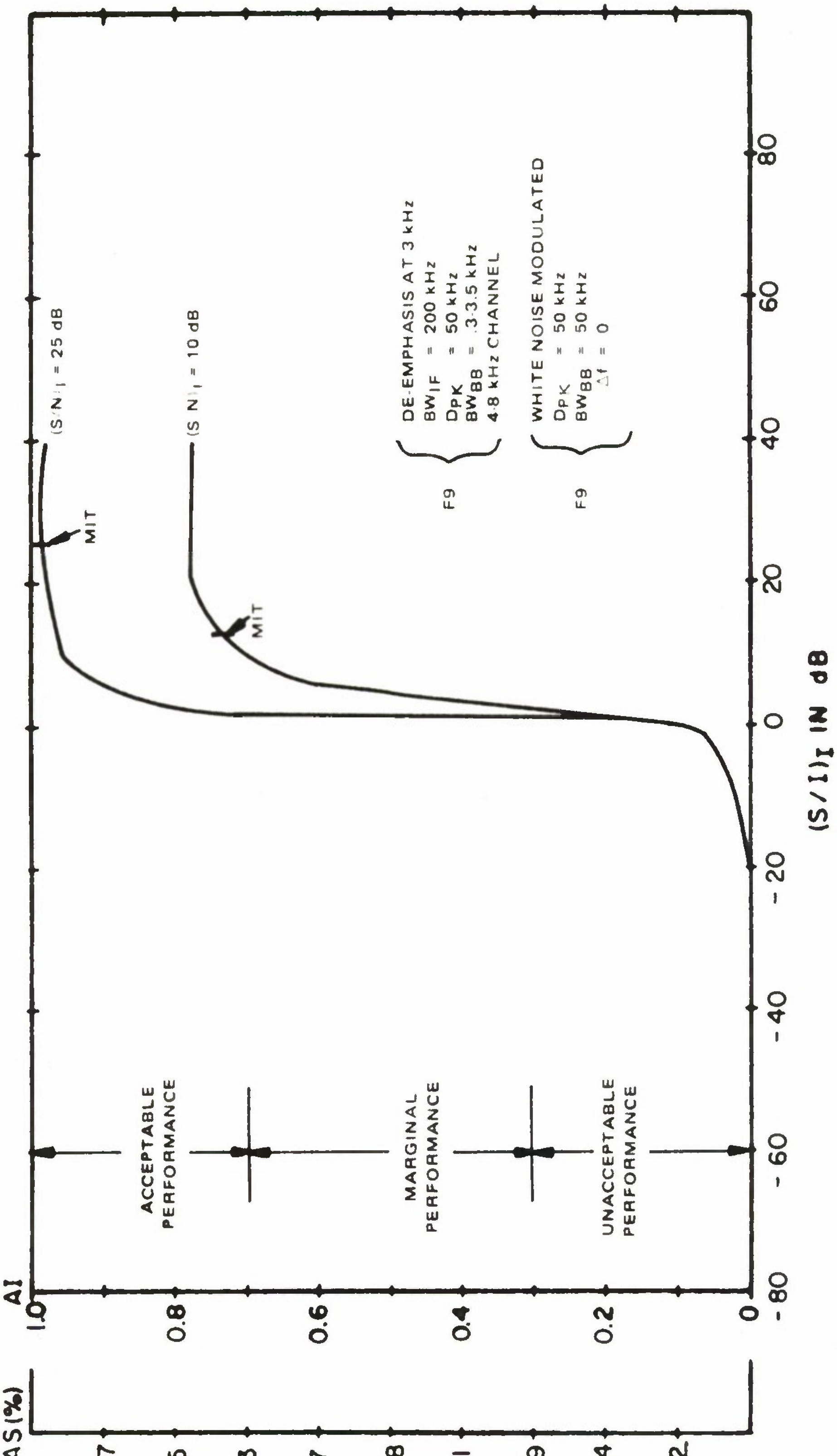


Figure III-90. Performance Degradation Curve For F9 Receiver With F9 Interference (4-8 kHz Lower Channel, Δf = 0 Hz)

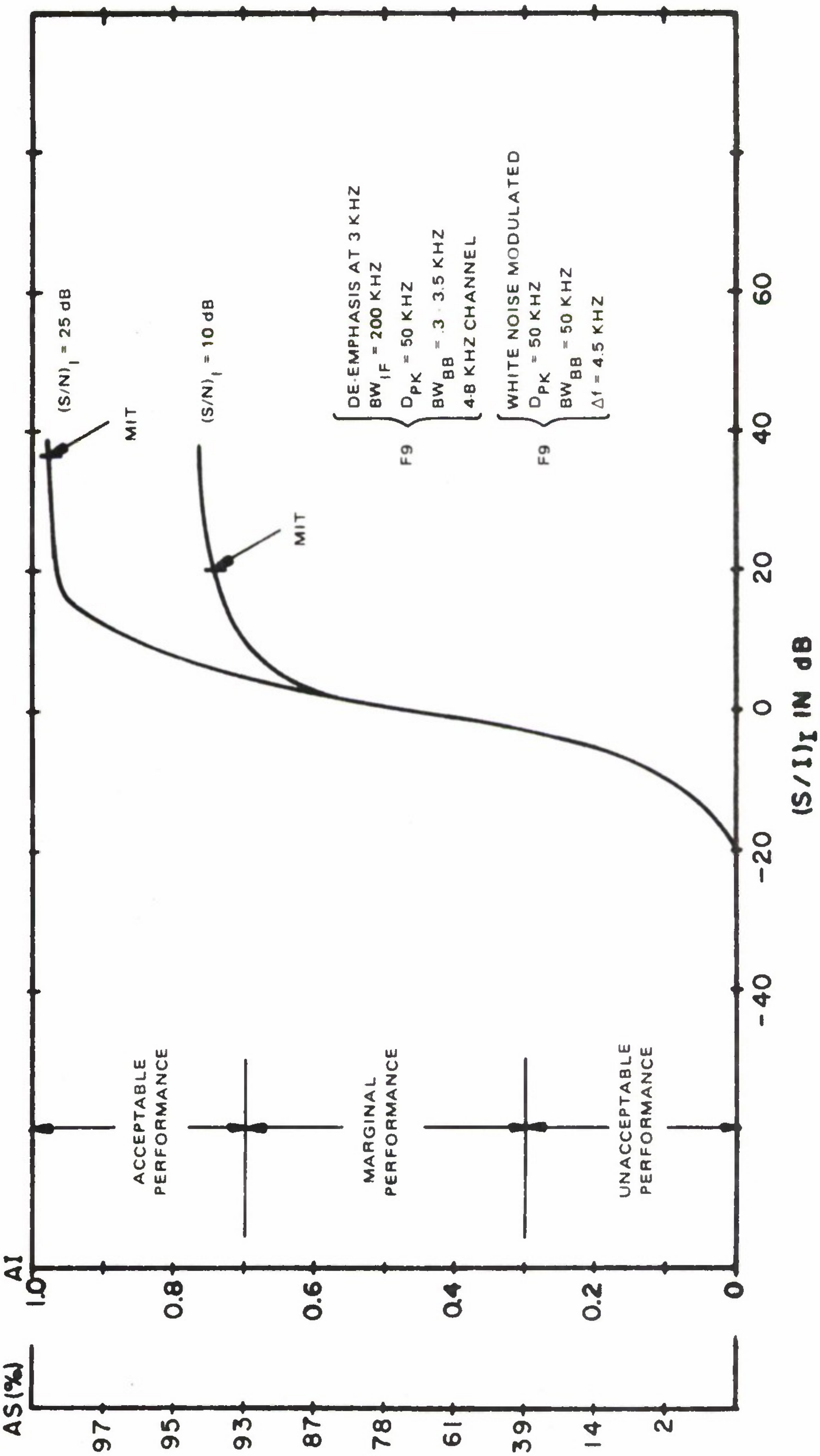


Figure III-91. Performance Degradation Curve For F9 Receiver With F9 Interference (4-8 kHz Lower Channel, Δf = 4.5 kHz)

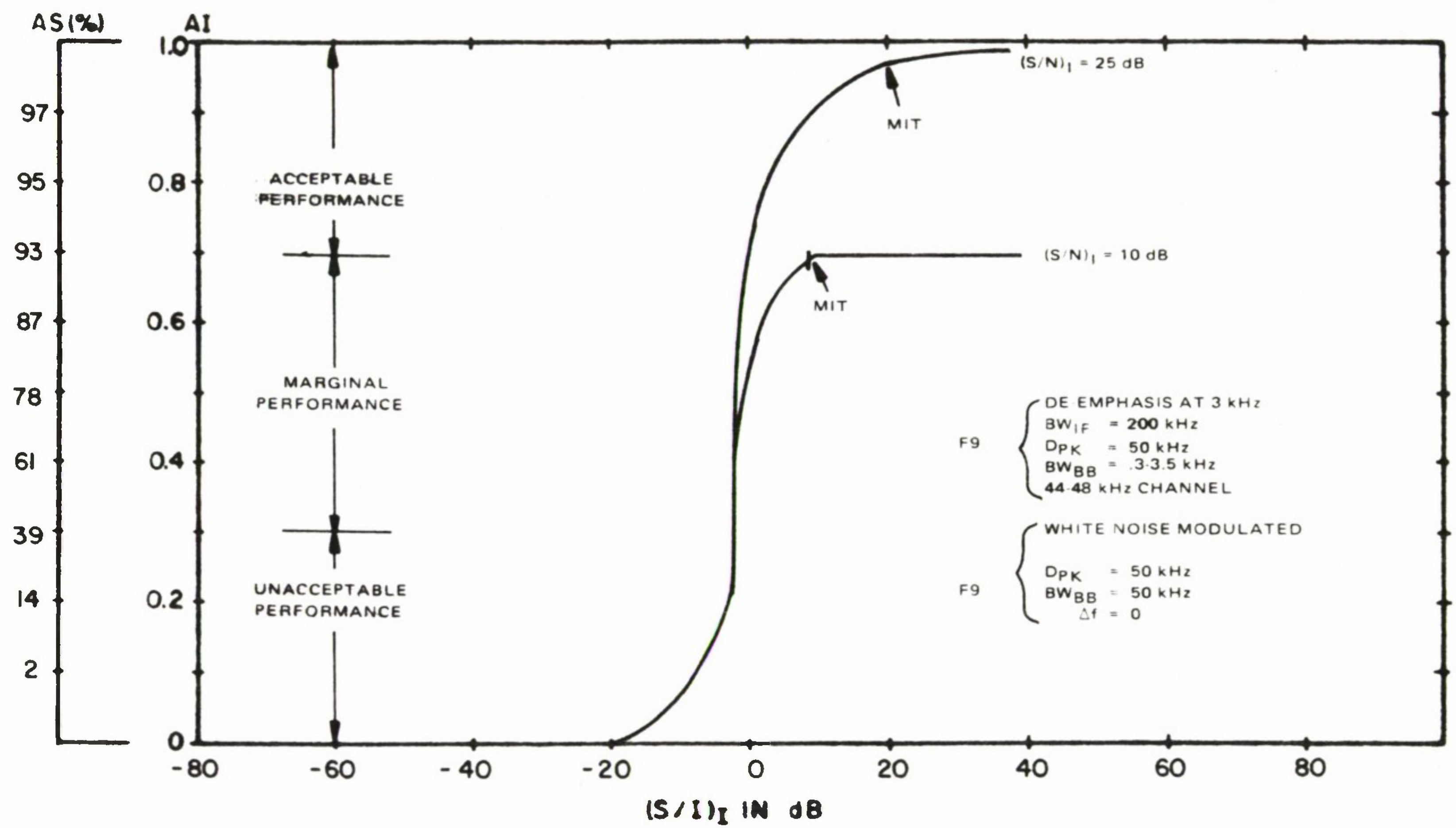


Figure III-92. Performance Degradation Curve For F9 Receiver With F9 Interference (44-48 kHz Upper Channel, Δf = 0 Hz)

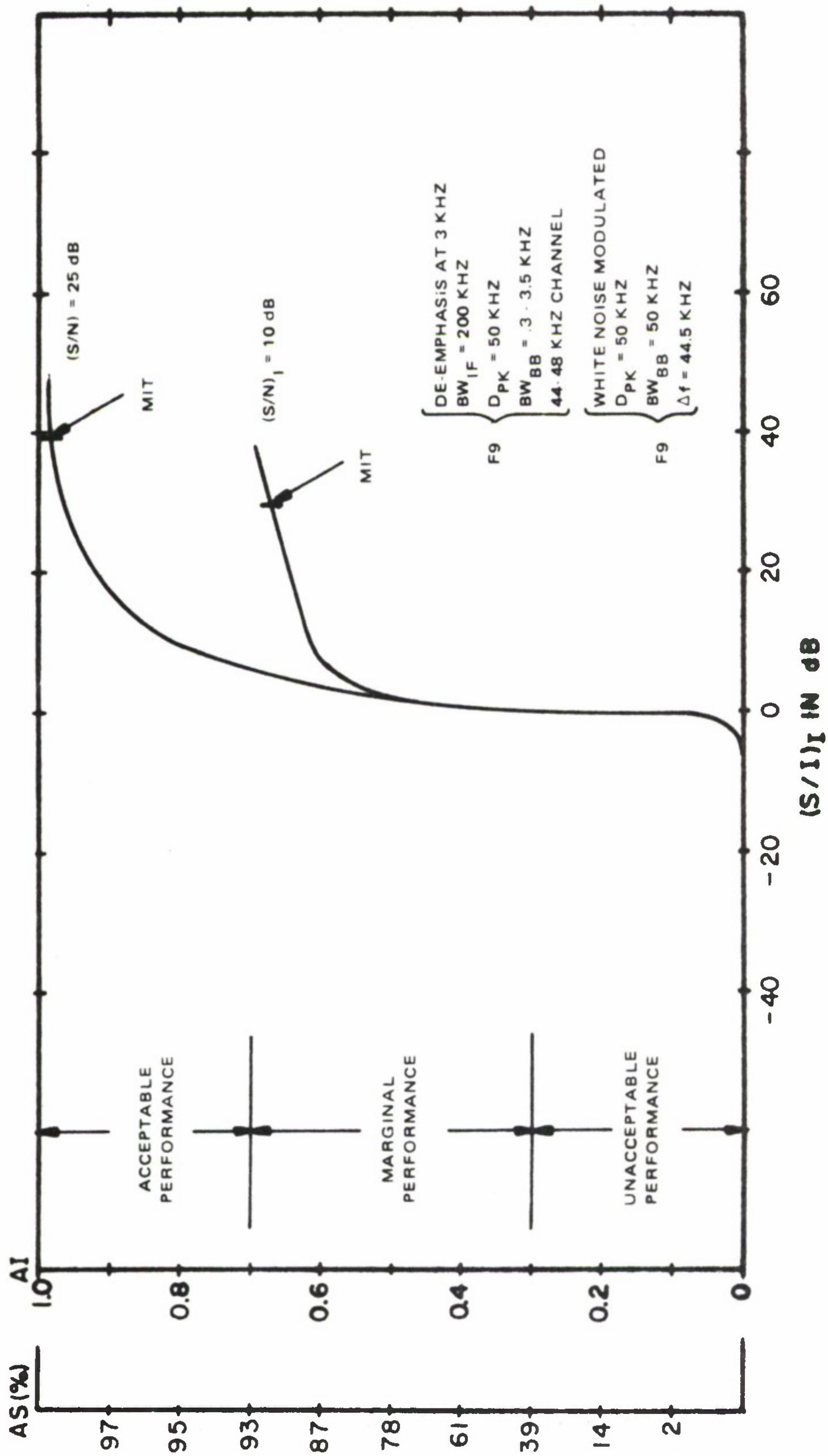


Figure III-93. Performance Degradation Curve For F9 Receiver With F9 Interference (44-48 kHz Upper Channel, Δf = 44.5 kHz)

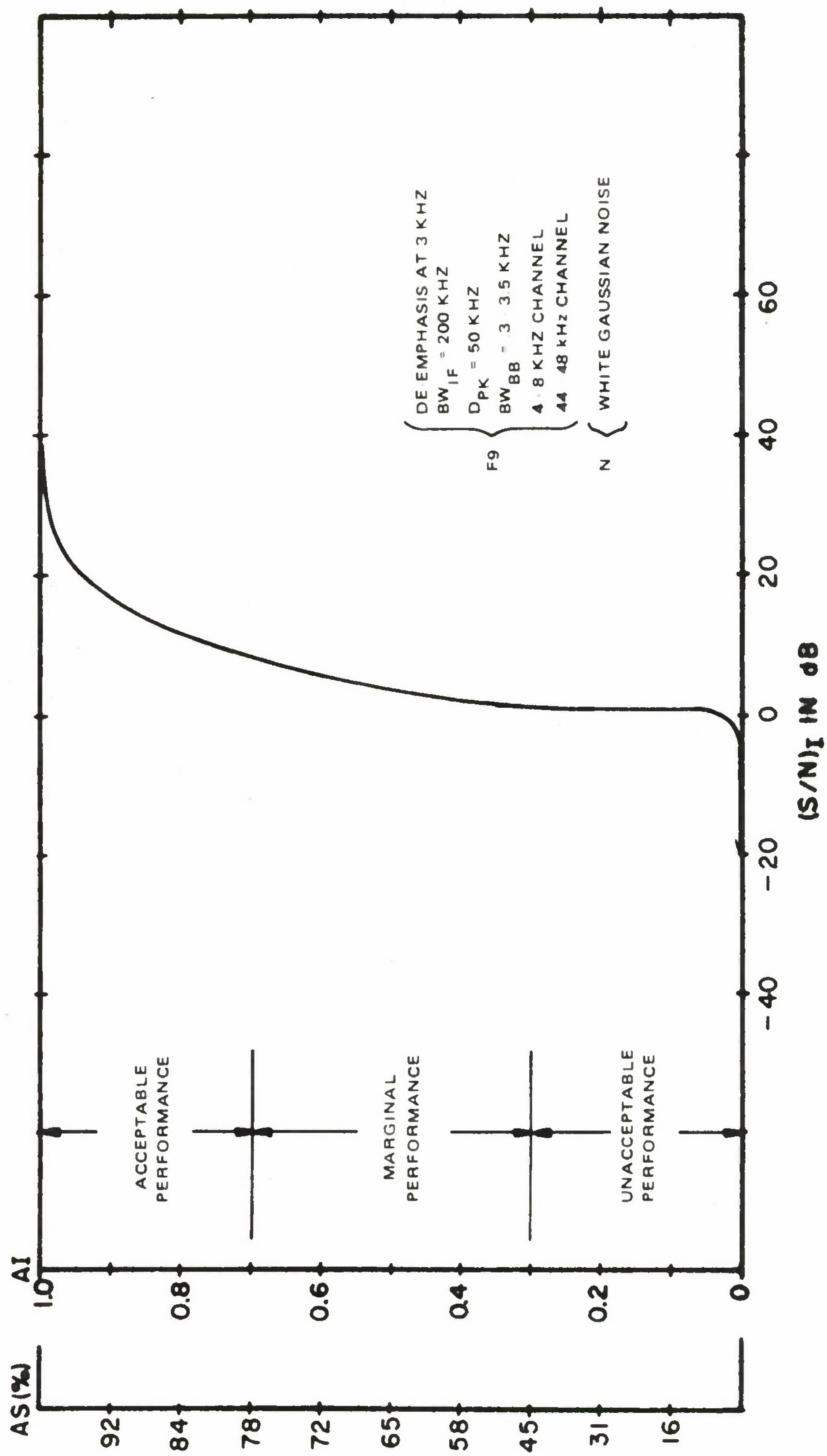


Figure III-94. Performance Degradation Curve For F9 Receiver With Noise

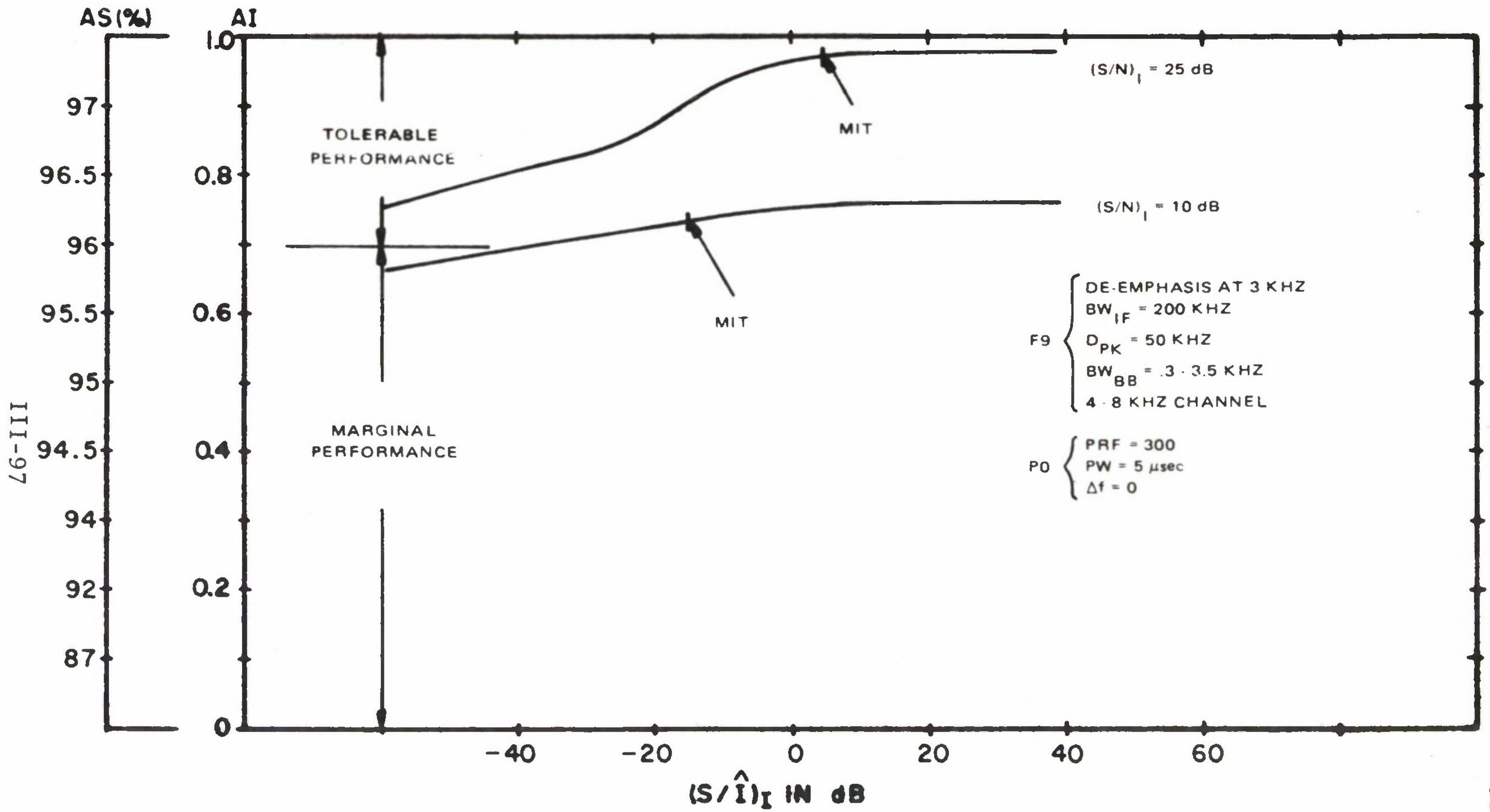


Figure III-95. Performance Degradation Curve For F9 Receiver With PO Interference (4-8 kHz Lower Channel, Δf = 0 Hz)

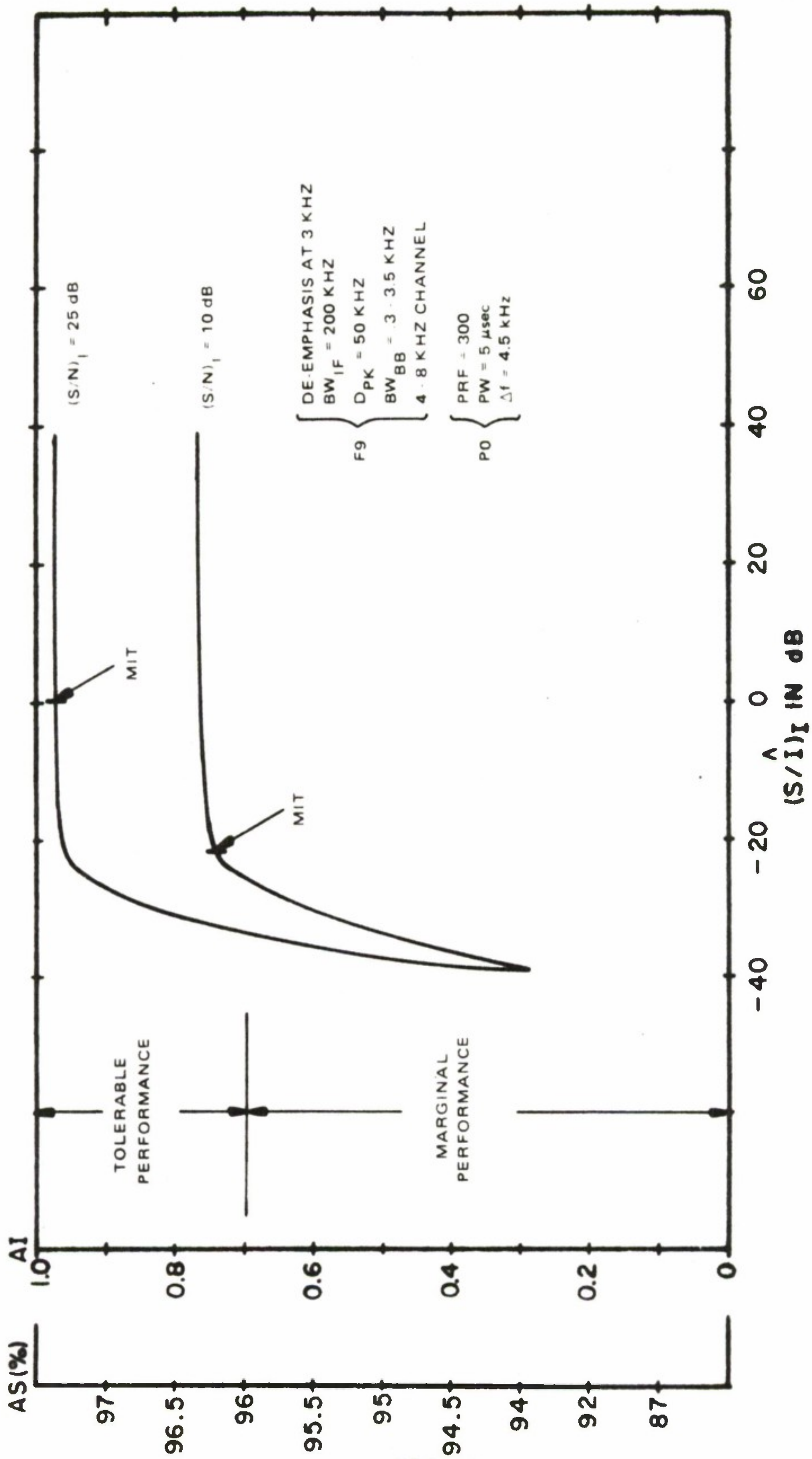


Figure III-96. Performance Degradation Curve For F9 Receiver With PO Interference (4-8 kHz Lower Channel, Δf = 4.5 kHz)

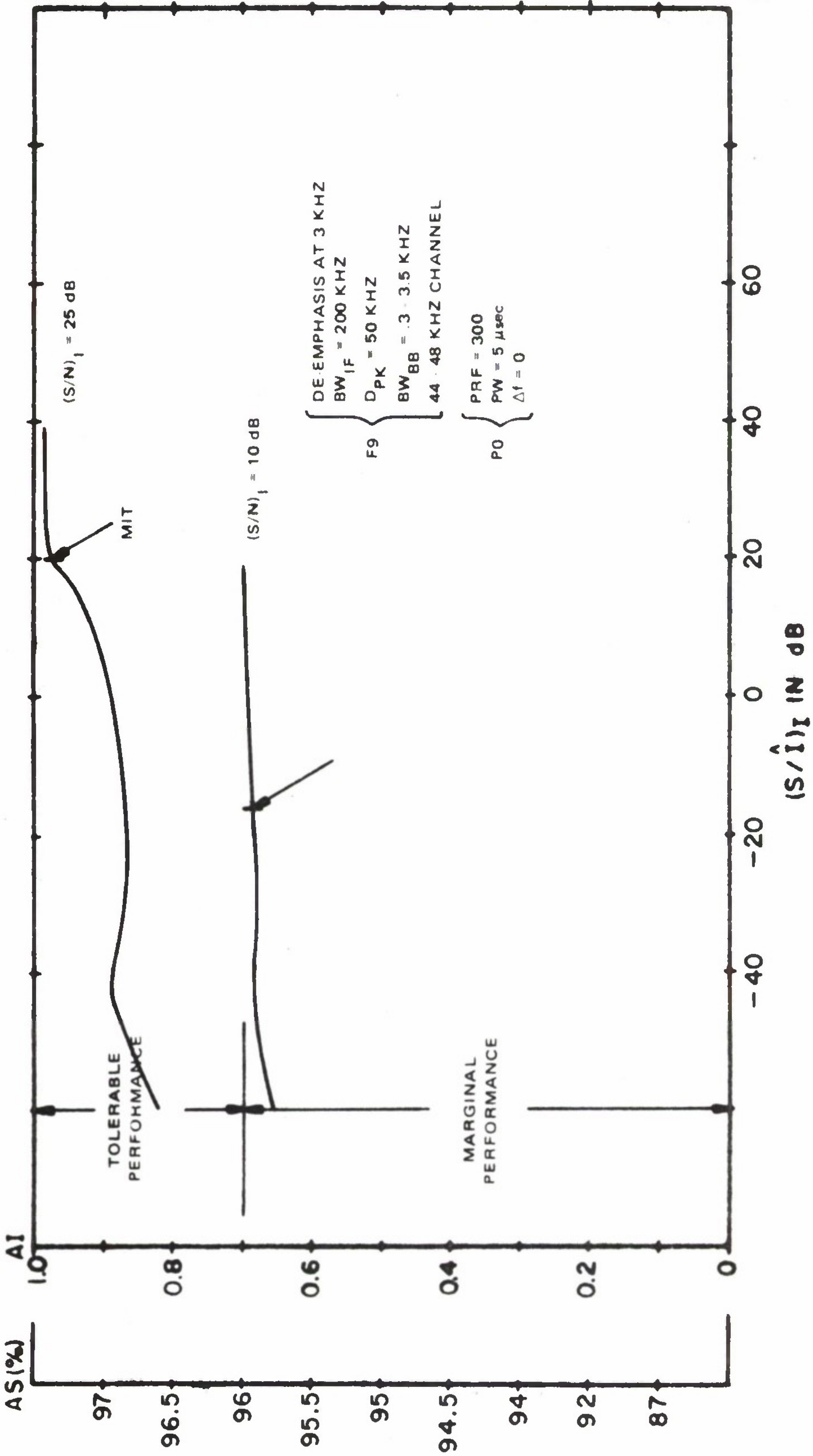


Figure III-97. Performance Degradation Curve For F9 Receiver With PO Interference (44-48 kHz Upper Channel, $\Delta f = 0$ Hz)

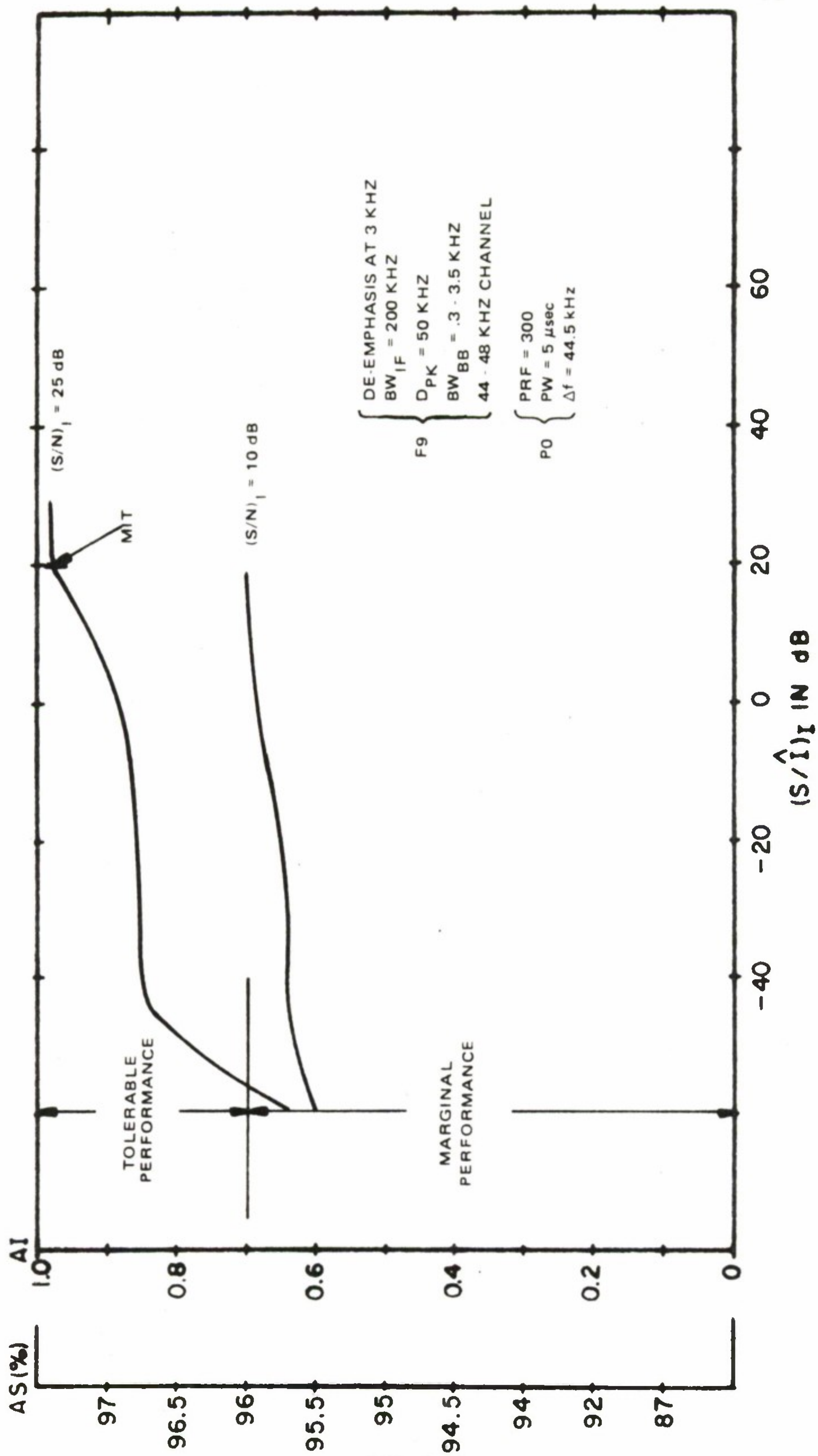


Figure III-98. Performance Degradation Curve For F9 Receiver With PO Interference (44-48 kHz Upper Channel, Δf = 44.5 kHz)

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ABSTRACT

The Receiver Performance Degradation Handbook provides reference curves for determining receiver performance as a function of input signal-to-interference ratio. The performance degradation curves were obtained using both simulation models and measured data. The desired signal modulation types considered are A2, A3, A3J, A9B, F1, F3 and F9. The interference modulation types are A1, A3, A3J, A9B, F1, F3, F9, PO and noise.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
DEGRADATION RECEIVER PERFORMANCE SIGNAL-TO-INTERFERENCE RATIO ELECTROMAGNETIC COMPATIBILITY						